PB-217 036

DEVELOPMENT OF CONSTRUCTION AND USE CRITERIA FOR SANITARY LANDFILLS

Consumer Protection and Environmental Health Service
Washington, D. C.

1969

DISTRIBUTED BY:

NTIS
National Technical Information Service
U. S. DEPARTMENT OF COMMERCE
5285 Port Royal Road, Springfield Va. 22151

PB 217 036

DEVELOPMENT OF CONSTRUCTION AND USE CRITERIA FOR SANITARY LANDFILLS

An Interim Report

Prepared by
County of Los Angeles, Department of County Engineer, Los Angeles,
and Engineering-Science, Inc., Arcadia, California,
under Grant No. DO1-UI-00046

Details of illustrations in
this document may be better
studied on microfiche

Reproduced by
NATIONAL TECHNICAL
INFORMATION SERVICE
U S Department of Commerce
Springfield VA 22151

U.S. DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
Public Health Service
Consumer Protection and Environmental Health Service
Environmental Control Administration
Bureau of Solid Waste Management
Cincinnati
1969

PREFACE

An estimated 900 million pounds of solid wastes of all types are produced in the United States every day. What to do with these solid wastes, how to dispose of them without needlessly endangering public health and welfare, and how to recover and reuse valuable materials now "thrown away" are among the most challenging and perplexing of current national problems. Because of lack of suitable planning, interest, and public understanding, these problems have reached such proportions that nationwide attention is demanded and action for the development of adequate solutions must be taken.

Intensified action concerning these problems was made possible by the Solid Waste Disposal Act, Title II of Public Law 89-272, which was signed by the President on October 20, 1965. This legislation directs the Secretary of the Department of Health, Education, and Welfare to initiate, encourage, and support a national program aimed at discovering and evaluating better methods of coping with the solid waste problem.

The Secretary is authorized (1) to conduct and support research on the nature and scope of the problem, on methods of more safely and efficiently collecting and disposing of solid wastes, and on techniques for recovering from solid wastes potentially valuable materials and energy; (2) to provide training and financial and technical assistance to local and State agencies and other organizations in the planning, development, and conduct of solid waste management programs; (3) to encourage and support projects that may demonstrate new and improved methods of solid waste collection, handling, and disposal.

To carry out these responsibilities, the Bureau of Solid Waste Management was established. Among the responsibilities with which the Bureau is charged is that of providing grant support for demonstrations relating to the development and application of new and improved methods of solid waste collection, storage, processing, and ultimate disposal; and also for studies and investigations that may lead to a demonstration of improved disposal practices, or may provide solutions for regional or national solid waste disposal problems. Associated with this is the responsibility of collecting and making available by appropriate means the results of, and other information pertaining to, such federally supported demonstrations, studies, and investigations.

Accordingly this report has been reproduced to disseminate as widely as possible the latest available information and findings of a project that has received grant support from the Bureau of Solid Waste Management. It is hoped that it will provide those working in this field with useful information that will be of assistance in developing approaches to the solutions of their solid waste disposal problems.

--RICHARD D. VAUGHAN, ***Director***
Bureau of Solid Waste Management

ABSTRACT OF DEMONSTRATION GRANT NO. D01-UI-00046

TITLE: Development of Construction and Use Criteria for Sanitary Landfills

PROJECT TYPE: Study & Investigation

GRANTEE: County of Los Angeles
Hall of Administration
500 West Temple Street
Los Angeles, California 90012

PROJECT DIRECTOR: John A. Lambie, County Engineer
County Engineering Building
108 West Second Street
Los Angeles, California 90012

ESTIMATED TOTAL PROJECT COSTS:	$303,500
GRANTEE'S SHARE:	$101,270
FEDERAL SHARE: (by year of project life)	$ 66,330 - 01 $ 73,300 - 02 $ 62,600 - 03

DATE PROJECT STARTED: Jan. 1, 1967

DATE PROJECT ENDS: Dec. 31, 1969

OBJECTIVES: (1) The development of methods to control gas movements from existing and new landfills; (2) the development of methods to control leachate discharging from existing and new landfills; (3) the development of a "code" for use in controlling construction of buildings on completed sanitary landfills.

PROCEDURES: The actual investigations will be made jointly by Engineering-Science, Inc., Arcadia, California, and the County's technical staff.

First Year. Provide solutions to the problem of decomposition-gas movement from sanitary landfills into surrounding soil and groundwaters. These solutions will be the result of studies of: gas flow measurements, geologic configurations, soil properties, subsidence rates, and gas control devices. Second Year. Continue to investigate subsidence in sanitary landfills. The investigations will include: (1) a review of subsidence data obtained from other on-going solid waste disposal projects; (2) surveys of existing structures located on landfills in Los Angeles and San Francisco areas; (3) evaluation of settlement data; (4) studies of the effects of settlement on structures, utilities, and roadbeds; (5) recommendation for construction of above facilities on sanitary landfill sites. Third Year. The findings from the first and second years will be combined and evaluated to provide specific design and construction guidelines for sanitary landfills in urbanized areas. Solutions to subsidence problems will be developed, pilot experiments to demonstrate the advantages of volume reduction prior to landfilling will be conducted, salvage of materials will be studied, and a control and inspection system for landfill operations will be formulated. Throughout the study, specific proposals for demonstration projects will be formulated.

ic

First Annual Report

DEVELOPMENT OF CONSTRUCTION AND USE CRITERIA FOR SANITARY LANDFILLS

Prepared Under Grant No. 1-D01-SW-00046-01

DEPARTMENT OF HEALTH, EDUCATION, AND WELFARE
PUBLIC HEALTH SERVICE
SOLID WASTES PROGRAM

Prepared by

The County of Los Angeles
Department of County Engineer
108 West Second Street
Los Angeles, California 90012

And

Engineering-Science, Inc.
150 East Foothill Boulevard
Arcadia, California 91006

October 1968

iD

NOTES ON REPORT ARRANGEMENT

Chapters are numbered with Roman numerals, with Arabic numerals used for page numbering within chapters.

Tables are numbered with Roman numerals which designate the chapter and with Arabic numerals which designate the sequence with the chapter.

Figures for all chapters are assembled at the back of the report except that photographs of studied research sites are included with the site descriptions in Chapter III.

Appendices are assembled together at the end of the report, prior to the figures.

References noted throughout the text are listed in Appendix A.

TABLE OF CONTENTS

		Page
CHAPTER I	INTRODUCTION	
	Background	I-1
	Project Objectives	I-2
	Management of the Study	I-3
	Acknowledgments	I-3
CHAPTER II	SANITARY LANDFILL PRACTICE	
	City of Los Angeles	II-3
	City of Burbank	II-4
	County of Orange	II-4
	County Sanitation Districts of Los Angeles County	II-5
	Private Operators	II-6
CHAPTER III	SELECTION OF LANDFILL SITES AND SCOPE AND RESULTS OF STUDIES	
	Site Identification and Selection	III-1
	General Soil Study for the Selected Landfills	III-2
	Gas Sampling Probe Installation	III-10
	Gas Sampling Procedure	III-14
	Gas Analysis	III-15
	Sanitary Landfill Subsidence	III-21
CHAPTER IV	GAS MOVEMENT THROUGH POROUS MEDIA	
	Theoretical Consideration	IV-1
	Experimental Method	IV-4
	Results of Experiments	IV-8
	Analysis of Results	IV-8
	Discussion of Experiment	IV-15
CHAPTER V	DESIGN AND IMPLEMENTATION OF FIELD GAS BARRIERS AND CONTROL DEVICES	
	Shallow Control Devices	V-1
	Deep Control Installations	V-2
	Barrier (Membrane) Construction	V-3
	Design of Field Gas Control Systems	V-6
	Development of a Device for Measuring Upward Movement of Methane through Sanitary Landfills	V-15
	Discussion of Design Considerations Related to Gas Movement in Soils	V-15
	Feasibility of Constructing Soil Membranes	V-17
CHAPTER VI	THE EFFECT OF SANITARY LANDFILLS ON GROUND WATER QUALITY	
	History	VI-1
	Potential Water Impairment from Sanitary Landfills	VI-3

TABLE OF CONTENTS (Continued)

		Page
CHAPTER VI	Effect on Ground Water	VI-13
	Project Investigation	VI-14
	Recent Findings	VI-15
CHAPTER VII	COMPLETED SANITARY LANDFILL LAND USES	
	Site No. 4	VII-1
	Site No. 8	VII-2
	Other Sites	VII-2
CHAPTER VIII	CODE CONSIDERATIONS FOR CONSTRUCTION AND USE OF SANITARY LANDFILLS	
	Los Angeles County Building Code	VIII-2
	Gas Control at Completed Refuse Fills	VIII-3
	Control of Future Refuse Fills	VIII-4
	Control of Ground Water Quality	VIII-4
CHAPTER IX	SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS	
	Summary	IX-1
	Conclusions	IX-4
	Recommendations	IX-5
	Recommended Research	IX-8

LIST OF TABLES

Table		Page
III-1	Scope of Study at Selected Landfill Sites	III-4
III-2	Results of Soil Analyses for Selected Landfill Sites	III-6
III-3	Settlement Record at Site No. 2-B	III-25
III-4	Settlement Record at Site No. 3	III-26
III-5	Settlement Record at Site No. 4	III-28
III-6	Settlement Record at Site No. 5	III-29
III-7	Cumulative Three-Year Settlement Record at Site No. 5	III-31
III-8	Cumulative Settlement and Lateral Movement Record at Site No. 7	III-32
III-9	Settlement Record at Site No. 9	III-33

LIST OF TABLES (Continued)

Table		Page
III-10	Settlement Record at Site No. 10	III-34
III-11	Settlement Record at Site No. 11	III-36
IV-1	Test Plan for Gas Diffusion Experiment	IV-7
IV-2	Diffusion-Dispersion Coefficients for Methane in Various Porous Media	IV-9
IV-3	Calculated Flow of Methane by Diffusion-Dispersion Through Soil Membranes	IV-11
IV-4	Calculated Rates of Flow of Methane Due to Pressure Gradient through Soil Membrane	IV-14
IV-5	Total Flow of Methane Through Soil Membranes	IV-14
VI-1	Typical Rubbish Compositions for Summer 1954	VI-5
VI-2	Analysis of Leachates from Landfill Refuse	VI-7
VI-3	Composition of Gases Produced from Landfill Refuse under Various Conditions	VI-10
VI-4	Solubility of Gases Associated with Landfills in Water	VI-12
VI-5	Results of Test Borings at Research Site No. 8 1968	VI-17

LIST OF APPENDICES

Appendix A	List of References Cited
Appendix B	Record of Landfill Construction
Appendix C	Gas Analysis Data Sheets
Appendix D	"Weathergard Fiberseal Liner" (Fiber Reinforced Sealer)
Appendix E	Glossary
Appendix F	Refuse Gas Burners

LIST OF FIGURES

Figure

III-1 Grain Size Distribution - Site No. 2-A

III-2 Grain Size Distribution - Sites No. 3, 4

III-3 Grain Size Distribution - Sites No. 4, 7, 9

III-4 Grain Size Distribution - Sites No. 5, 8

III-5 Grain Size Distribution - Site No. 6

III-6 Gas Collection Assembly

III-7 Typical Disassembled Gas Probe

III-8 Research Site No. 2
  Device on Dozer Ripper Tooth for Installing Gas Probe Tubing on Long Horizontal Runs

  Research Site No. 2
  Installing Plastic Tubing for Gas Probes in Earth Face

III-9 Research Site No. 2-A
  Gas Probe and Tubing Layout at Intermediate Stage of Dike Construction

III-10 Research Site No. 1
  Installing Gas Probe Beneath Asphalt Paved Area

  Research Site No. 4
  Drilling Hole for Gas Probe Installation

III-11 Typical Gas Probes Installed Through Wall of Sewer Manhole

  Withdrawing Sample from Gas Probe Installed Through Wall of Sewer Manhole

III-12 Methane Concentration - 26 July, 9 August 1967
  Site No. 1

III-13 Methane Concentration - 24 October 1967
  Site No. 1

III-14 Carbon Dioxide Concentration - 16 May 1967
  Site No. 2-A

III-15 Carbon Dioxide Concentration - 7 July 1967
  Site No. 2-A

III-16 Carbon Dioxide Concentration - 12 September 1967
  Site No. 2-A

LIST OF FIGURES (Continued)

Figure

III-17 Methane Concentration - 17 July 1967
Site No. 3

III-18 Methane Concentration - 24 January 1968
Site No. 3

III-19 Methane Concentration - 7 July 1967
Site No. 4

III-20 Methane Concentration - 21 February 1968
Site No. 4

III-21 Probe Location
Site No. 5

III-22 Methane Concentration - 8 February 1968
Site No. 6

III-23 Probe Location
Site No. 7

III-24 Methane Concentration - 9 May 1967
Site No. 8

III-25 Methane Concentration - 13 September 1967
Site No. 8

III-26 Methane Concentration - 27 July 1967
Site No. 9

III-27 Methane Concentration - 5 December 1967
Site No. 9

III-28 Research Site No. 4
Broken Pavement Indicates Unequal Settlement

Research Site No. 8
Cracked Wall Shows Results of Settlement

III-29 Monument Location
Site No. 2-B

III-30 Research Site No. 2-B
Surveying Monument System

III-31 Monument Location
Site No. 3

III-32 Monument Location
Site No. 4

LIST OF FIGURES (Continued)

Figure

III-33 Monument Location
Site No. 5

III-34 Research Site No. 5
Surveying Monument System

III-35 Monument Location
Site No. 7

III-36 Monument Location
Site No. 9

III-37 Monument Location
Site No. 10

III-38 Monument Location
Site No. 11 (Area 1)

III-39 Monument Location
Site No. 11 (Area 3)

IV-1 Schematic Diagram of Laboratory Unit for Study of Gas Diffusion in Porous Media

IV-2 Cross-Section of Laboratory Unit

IV-3 Sections Through Laboratory Unit

IV-4 Laboratory Unit for Study of Gas Diffusion in Porous Media

IV-5 Grain Size Distribution
Sand

IV-6 Grain Size Distribution
Kaolin Clay

IV-7 Methane Concentration History
Test No. 1

IV-8 Methane Concentration History
Test No. 2

IV-9 Methane Concentration History
Test No. 3

IV-10 Methane Concentration History
Test No. 4

IV-11 Methane Concentration History
Test No. 5

LIST OF FIGURES (Continued)

Figure

IV-12 Methane Concentration History
Test No. 6

IV-13 Methane Concentration History
Test No. 7

IV-14 Methane Concentration History
Test No. 8

IV-15 Methane Concentration History
Test No. 9

IV-16 Methane Concentration History
Test No. 10

IV-17 Methane Concentration History
Test No. 11

IV-18 Methane Concentration History
Test No. 12

IV-19 Methane Concentration History
Test No. 13

IV-20 Methane Concentration History
Test No. 14

IV-21 Methane Concentration History
Test No. 15

V-1 Research Site No. 4
Gas Control Device Installed to Burn Gas and Eliminate Odors

Research Site No. 8
Gas Control Device

V-2 Control System Plan
Site No. 1

V-3 Control System Details
Site No. 1

V-4 Research Site No. 5
Sub-barrier Probe Installation

Research Site No. 5
Sub-barrier Venting Pipe

LIST OF FIGURES (Continued)

Figure

V-5 Research Site No. 5
Barrier Initial Prime Coat Application

Research Site No. 5
Barrier Liner Installation

V-6 Research Site No. 5
Barrier Final Seal Coat Application

Research Site No. 5
Upper Probe Layout

V-7 Research Site No. 5
Greenhouse Gravel Floor Placement

Research Site No. 5
Greenhouse Construction

V-8 Control System
Site No. 5

V-9 Control System Plan and Details
Site No. 8

V-10 Portable Field Methane Sensor

VI-1 Original Pit Contours (Flood Control Map 1954) and
Test Boring Locations -- Site No. 8

VI-2 Section A-A -- Site No. 8

VI-3 Section B-B -- Site No. 8

CHAPTER I

INTRODUCTION

BACKGROUND

The County of Los Angeles, State of California, is conducting a three-year program of research and investigation for the development of construction and use criteria for sanitary landfills. The program was developed in cooperation with the Solid Wastes Program, National Center for Urban and Industrial Health, United States Public Health Service, Department of Health, Education, and Welfare, and is funded, in part, through Solid Waste Disposal Study and Investigation Grant No. 1-D01-SW-00046-01. On March 7, 1967, Engineering-Science, Inc., was engaged by the County of Los Angeles to assist in the conduct of the study in the capacity of principal consultant to the County.

It is recognized that the disposal of solid wastes by sanitary landfill is one of the most practical, economical, and simplest methods available for many areas within the United States. The practice of sanitary landfilling is used almost exclusively in Los Angeles County and will undoubtedly continue for many years as the principal method for disposal of solid wastes. However, the apparent simplicity of the sanitary landfill method does not obviate the need for competent planning, investigation, and control of the operation in order to avoid potential problems. The principal problems relating to improperly placed sanitary landfills are decomposition gases, formation and movement of leachates (causing possible impairment of water quality), and unequal settlement of the completed landfill surfaces. These problems can restrict the beneficial use of such completed landfills. The sanitary landfill will continue to be an ideal method of solid waste disposal for Los Angeles County and other similar areas of the country if these problems are recognized and proper construction techniques are developed and followed. If empty gravel pits (which are considered hazardous and unsightly) and useless canyons can be filled with solid wastes without endangering the environment, their surfaces can be made available for recreational, industrial, parking, and other beneficial uses.

The goal of the first year program was to formulate practical solutions to control the refuse gas movement; continued investigation of land subsidence in finished sanitary landfills and a study of various land uses of existing landfills will be undertaken during the second year of this program; comprehensive criteria for construction and use of sanitary landfills will be developed in the third year program.

This report represents the results of the research carried out during the first year of the program. It should be noted, that the results to date are derived from the study of specific conditions in just one locale, with parameters representative of said locale, and thus may not be completely applicable for parameters associated with other areas.

PROJECT OBJECTIVES

The detailed objectives of the first-year study program were as follows:

(1) To study the state-of-the-art in construction and operation of sanitary landfills with emphasis on current practices in Los Angeles County.

(2) To evaluate the problem of gas movement from a selected number of sanitary landfills in Los Angeles County in order to determine the general direction and the extent of gas movement from these landfills; and to determine correlation between direction and extent of gas movement and surrounding soil characteristics.

(3) To conduct a literature and data research on the possible impairment of ground water quality by sanitary landfills.

(4) To conduct laboratory experiments for testing the effectiveness of various natural soils in reducing outward movement of gases from sanitary landfills; with experiments planned so that the results will materially aid in developing practical methods for the control of gas movement from sanitary landfills in Los Angeles County as well as in other locations throughout the United States; and utilizing results to form a basis for developing standard codes for the design and operation of future landfills.

(5) To develop theoretical and practical methods for controlling gases generated in landfills; with emphasis placed on developing barriers, gas collector devices, and other techniques.

(6) To conduct all necessary work such as gas sampling and analysis, land settlement survey, and planning for future stages of the project which are essential for the successful conclusion of the study.

MANAGEMENT OF THE STUDY

Mr. John A. Lambie, County Engineer, served as Project Director. All aspects of the study were under the direct supervision of Mr. Carroll D. Smith, Division Engineer, Industrial Waste Division. Assisting Mr. Smith were Mr. Charles G. Brisley, Jr., Assistant Division Engineer, and Mr. Kenneth Harvey, Civil Engineer.

Engineering-Science, Inc. personnel participating in the project were under the direction of Dr. Harvey F. Ludwig, and included Mr. Ralf C. Carter, Dr. Houshang Esmaili, Mr. Robert E. Franklin, Dr. Philip N. Storrs, and Mr. G. Scott Robertson. Mr. Donald R. Anderson and Mr. Richard E. Dowd assisted in the initial phases of the project.

ACKNOWLEDGMENTS

Representatives and staff members of the County Sanitation Districts of Los Angeles County, the Bureau of Sanitation of the City of Los Angeles, the Orange County Road Department, and many other public agencies and private owners of landfill sites participated in various activities during the first year study and their cooperation and generous assistance are sincerely appreciated.

CHAPTER II

SANITARY LANDFILL PRACTICE

A sanitary landfill has been defined by the committee on Sanitary Landfill Practice of the Sanitary Engineering Division of the American Society of Civil Engineers as "---a method of disposing of refuse on land without creating nuisances or hazards to public health or safety, by utilizing the principles of engineering to confine the refuse to the smallest practical volume, and to cover it with a layer of earth at the conclusion of each day's operation or at such more frequent intervals as may be necessary."

Landfill disposal may be part of a planned activity of land reclamation whereby marginal lands (swamps, bogs, steep ravines, etc.) are converted into areas with potential recreational or economic use benefits. More often, however, landfill disposal represents the most economical method of solid waste disposal available to the community; costs of land acquisition, landfill operation, and pollution control as well as hauling costs are considered as costs attendant to solid waste disposal.

Planning and operation of a sanitary landfill must include provisions for control of water pollution, control of odor and nuisance, and elimination of disease carrying vectors.

Prevailing methods of sanitary landfill construction are generally divided into three categories (Reference 1) which are briefly described as follows:

(1) The trench method (also known as the trench-fill, or cut-and-cover method) is usually employed where flat or gently sloping land is the only marginal land available for solid waste disposal. The method is particularly suited to terrain which can be trenched with conventional earth-moving equipment and is based on the use of parallel excavated trenches. Starting at one edge of the land parcel, refuse is dumped into the first trench from its nearest side. At the end of each day's dumping and spreading, the refuse is covered with earth excavated from the second trench on the far side of the dumping edge. The

completed top is given a heavy earth cover while the working face is given a light closing cover. When completed, the landfill consists of a series of long, narrow refuse cells in parallel rows. The finished grade will usually be higher in elevation than the original ground surface.

(2) The area method (also known as the area-fill or fill-and-cover method) is usually employed in low-lying areas such as tidelands, marshes, or swamps and where land depressions such as abandoned quarries, ravines, or canyons are available. In tideland applications, the site is usually enclosed with a dike. Refuse is dumped on the existing ground surface, spread in horizontal layers, and compacted. At the end of each day's work the surface is covered as needed with earth excavated from the area directly in front of the working face of the landfill (progressive excavation). If excavation is not possible the fill is covered with imported cover material.

(3) The ramp method (also known as the progressive-slope method) is used exclusively in filling natural or man-made depressions, such as deep ravines, canyons, or quarries. In this method, the refuse is deposited and spread in layers on an angle against the side of the ravine, canyon or quarry to a predetermined height. This height can extend to 40 to 50 feet or higher. Cover soil is placed on the slope sides and top at regular intervals. In this operation, the collection vehicles deposit their refuse at the base of the working face of the fill; cover is obtained from a point just ahead of the face.

Sanitary landfilling can and does employ a wide variety of earthmoving equipment. The principal types in general use are wheeled tractor bulldozers, crawler or track-type tractor bulldozers, crawler tractors with bull clam or a front end loader, carrying scrapers, and cranes with draglines or other types of equipment. More specialized wheeled tractor-compactor bulldozers equipped with special type compactor wheels and refuse spreading blades are also being used.

Following is a brief description of the current practice in sanitary landfill construction in the Los Angeles area.

CITY OF LOS ANGELES

The Bureau of Sanitation of the City of Los Angeles operates three sanitary landfills disposing of approximately 4,000 tons of solid wastes per day. In addition, the City has regulatory control over any other landfill operations within the City. All such operations are issued permits only after a thorough analysis of the proposed fill's conformity with the public interest by the Board of Public Works. Specific regulations are set for each permit.

The Board of Public Works has adopted minimum standards for operation of landfills in the City of Los Angeles which are amended as necessary from time to time. Currently the procedures described in these regulations may be summarized as follows:

In general all fills are a cell "fill and cover" type operation with waste materials dumped, spread out, and compacted by repeated passes with a bulldozer in successive layers not more than three feet in compacted depth except for solid, non-combustible material larger than three feet in its smallest dimension. Watering is allowed to aid compaction, provided the quantity and quality of water applied and the method or location of application does not result in ponding to an extent that may cause leaching from the waste material into the underground water. Whenever the compacted refuse material reaches a maximum depth of nine feet, the surface of the fill must be leveled, compacted, and covered with at least nine inches of earth, sand, or equivalent approved materials. In addition, all waste materials must be covered with earth by midnight of the day when the waste material is dumped or deposited, with the exception of any working face which has a slope of one to one or more. The working face, however, must be properly maintained and compacted and must be covered if the same spot is not going to be used during the next day's operations. The working face is limited for each bulldozer working on the site. Upon completion of each lift, a final seal of a minimum of two feet of well-compacted materials must be applied to the top and all other surfaces, including the completed working face. The slope of any finished surface may not exceed 30 degrees from the horizontal.

At the sites operated by the Bureau of Sanitation, all refuse received for disposal is compacted and covered at the close of each day's operation. To insure that this is done, special lighting equipment has been provided to enable safe night operations when necessary. Cover material is applied to the fill surfaces and slopes in sufficient depth to permit vector control. Canyon landfill slopes are constructed with not less than six feet of earth, measured vertically on the slope, as final cover. Fill surfaces, when completed, are maintained with not less than four feet of earth as final cover. Paved maneuvering areas are maintained for use during inclement weather in locations where the natural soil does not permit truck travel in wet weather.

CITY OF BURBANK

The City of Burbank operates a large canyon-type fill in much the same manner as previously outlined for the City of Los Angeles. The fill is constructed by a cell-type fill and cover operation. Waste materials are dumped, spread out, and compacted by bulldozers in successive layers of four feet compacted depth. Earth cover is placed to a depth of approximately two feet on each four-foot lift, and an earth cover is also placed at the end of each day's operation. In general, rubbish is dumped within the cell and is spread and compacted on the working face of the area. A sheepsfoot roller is used for final compaction of the cover material.

There is no separation of rubbish, and water is used to aid in the compaction of refuse material.

The final cover depth of a completed lift is two feet of well compacted earth. The front face of the completed fill is maintained with a slope of approximately three to one.

COUNTY OF ORANGE

Refuse disposal sites within the County of Orange are operated by the County Road Department. Refuse transportation and transfer facilities are also operated by the County Road Department.

Refuse arriving at the disposal sites is separated into categories of demolition wastes, inert wastes, commercial wastes and domestic wastes. Each category is deposited at different locations within a fill site. Segregation of wastes is practiced primarily to facilitate control of traffic and unloading operations.

Both canyon and area types of fills are used and construction is based on the cell type fill and cover operation. Each cell varies in size from 2,500 to 5,000 square feet; the average lift height in each cell is 15 feet. The slope of the working face (as well as the finished face) varies from 2:1 to 3:1. Refuse is dumped both at the top of the fill and at the bottom of the working face. Bulldozers spread and compact the refuse in both directions on the working face with final compaction being accomplished by steel-wheeled compactors. The earth cover thickness for each lift averages one foot, with a minimum of three feet of cover being placed on all finished areas. A minimum earth cover is placed at the end of each work day. No water is added to the rubbish in the Orange County landfilling operations.

COUNTY SANITATION DISTRICTS OF LOS ANGELES COUNTY

The Sanitation Districts operate five sanitary landfills in Los Angeles County, disposing of approximately 10,000 tons of solid waste each day. The landfill sites are open to the public. The basic tool for placing and compacting the refuse is a crawler tractor of about 65,000 pounds gross weight equipped with a U-type bulldozer blade. Whenever operationally possible, refuse trucks discharge their load at the bottom of the working face and the tractors push the refuse up the working face, spreading and compacting it at the same time. The grade on the working face is maintained at about one vertical to five horizontal and the vertical height of each lift of refuse is approximately 20 feet. The grousers on the crawler's track crush and pulverize the refuse as the tractor moves up and down the slope. The loads are spread and compacted as received during the day.

At the end of each day the refuse is covered with a layer of earth sufficient to seal the day's refuse into a single cell. No refuse is left exposed at the end of the day's operation and the cover, as applied, is sufficient to prevent emergence of flies and the harboring of rodents. All final surfaces of the landfill are covered with a minimum of three feet of clean earth. The equipment used to cover refuse consists of self-propelled, twin-engine, rubber-tired scrapers. Sites handling smaller refuse volumes are equipped with 14 cubic yard scrapers and larger sites operate with 24 and 32 cubic yard scrapers.

PRIVATE OPERATORS

There are many privately operated landfill sites within the Los Angeles County area. These private operators are required to obtain permits from the County, cities of interest, and/or the State Water Quality Control Board. These agencies have established certain minimum standards and requirements which must be followed in the operation of sanitary landfills.

Operational procedures used by these private operators vary considerably, but most operators practice the fill and cover, cell-type method. The depths of lifts vary from four feet to fifty feet, with minimum earth covers of two feet or more. Spreading and compacting of rubbish is done by tractors traveling up and down the slope of the working face. Compacting is generally by bulldozers and water is sometimes used to augment compaction. Earthmoving equipment, carryalls, scrapers, etc., are usually used for excavations of pit areas, stockpiling of material, and covering of completed fills.

There are also a number of smaller, privately operated landfills in the Los Angeles area. These landfills are usually operated with shallow lifts, and earth cover is applied each day. The customary procedure is to spread and compact the refuse on a horizontal plane rather than by placing it on an advancing ramp or sloping face. The resulting compaction in these operations is usually good.

CHAPTER III

SELECTION OF LANDFILL SITES AND SCOPE AND RESULTS OF STUDIES

A comprehensive inventory of the existing sanitary landfills in the Los Angeles and San Francisco Bay Areas was prepared and reviewed to select a number of sites for conducting detailed gas movement and land settlement studies. The criteria utilized in selection of these sites is summarized as follows:

(1) The fill should have been completed or should be available without modifications over the planned three year study period.

(2) Original ground topography should be known.

(3) The type, quantity, and method of refuse placement with respect to elevation of the fill should be known.

(4) The thickness and type of final cover material should be known.

(5) Historic data relative to past settlement or gas movement is valuable, but not essential.

(6) Local geology should be known or be capable of reasonable assessment.

(7) Where private property is involved, cooperation of the individual land owner must be reasonably assured.

SITE IDENTIFICATION AND SELECTION

Sites selected for study are located within Los Angeles County, Orange County and the San Francisco Bay Area. Available historical records of sites are included in Appendix B.

Selected sites are identified by number, rather than by name or location.

Los Angeles County

Within Los Angeles County, 76 landfill sites were considered and were screened for compliance with the above stated requirements. Eight sites were selected for studies to be performed under the first year work program; settlement surveys, performed by another public agency, are reported herein for a ninth site. Plate A shows the general location of these sites in Los Angeles County.

Orange County

Because of a strong interest in the objectives of this study, representatives of Orange County cooperated in work for this project through installation of probes, collection and analysis of gas samples and installation and surveying of settlement monuments. This work was performed at one site within the County and results are presented herein.

San Francisco Bay Area

Seventy-seven waste disposal sites in the San Francisco Bay Area were reviewed for suitability for studying gas production and settlement in landfills subjected to tidal action. Certain legal problems of jurisdiction as well as the continued use of operating and completing sites for the disposal of excavated material from the Bay Area Rapid Transit project limited the final selection to only one site. This landfill is built in an area reclaimed from San Francisco Bay and is surrounded by dikes which keep seawater from overflowing the fill.

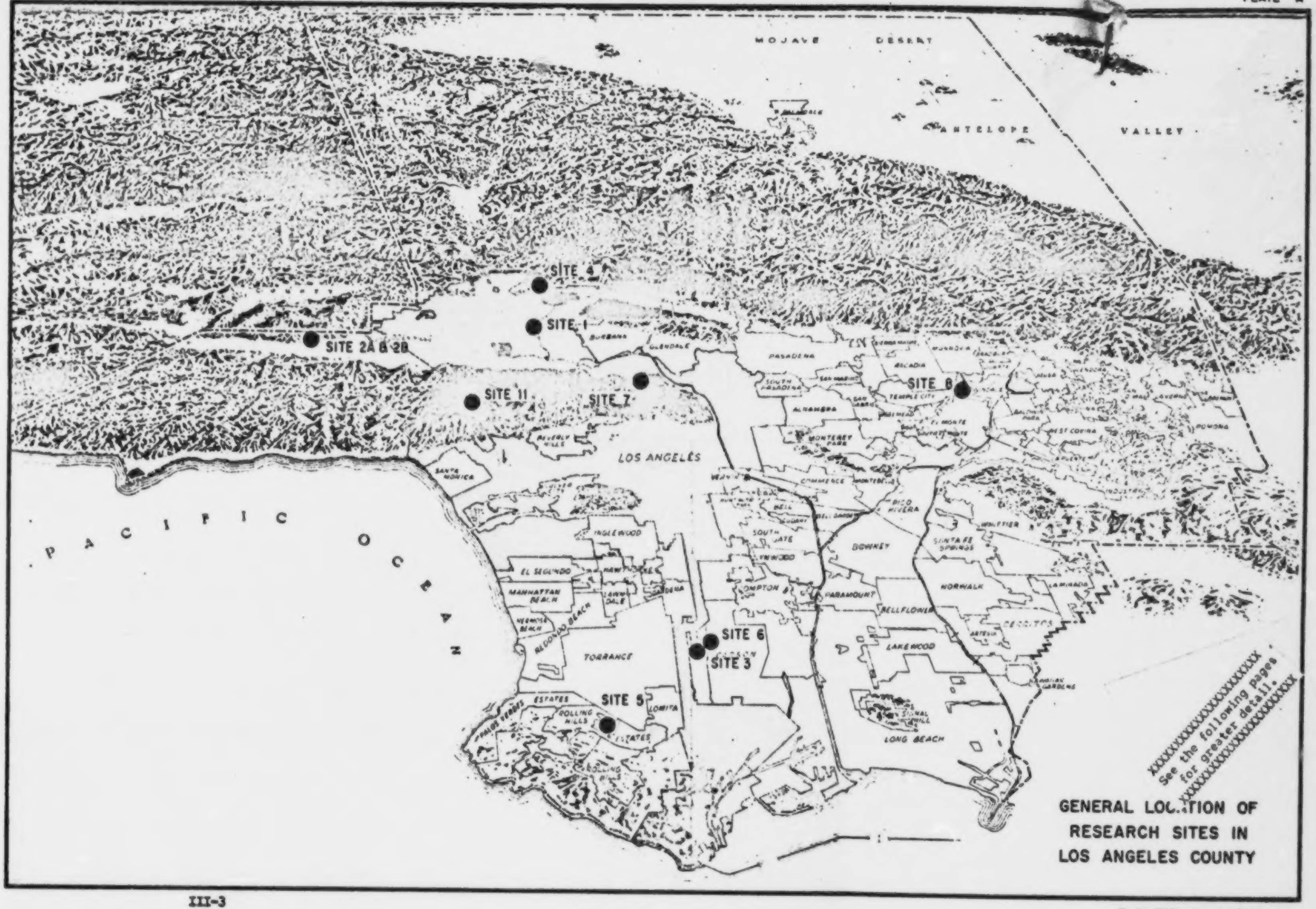
Summary

A summary of selected sites, together with the scope of study at each site, is shown in Table III-1. Photographs of some selected sites are shown in Plates B through K.

GENERAL SOIL STUDY FOR THE SELECTED LANDFILLS

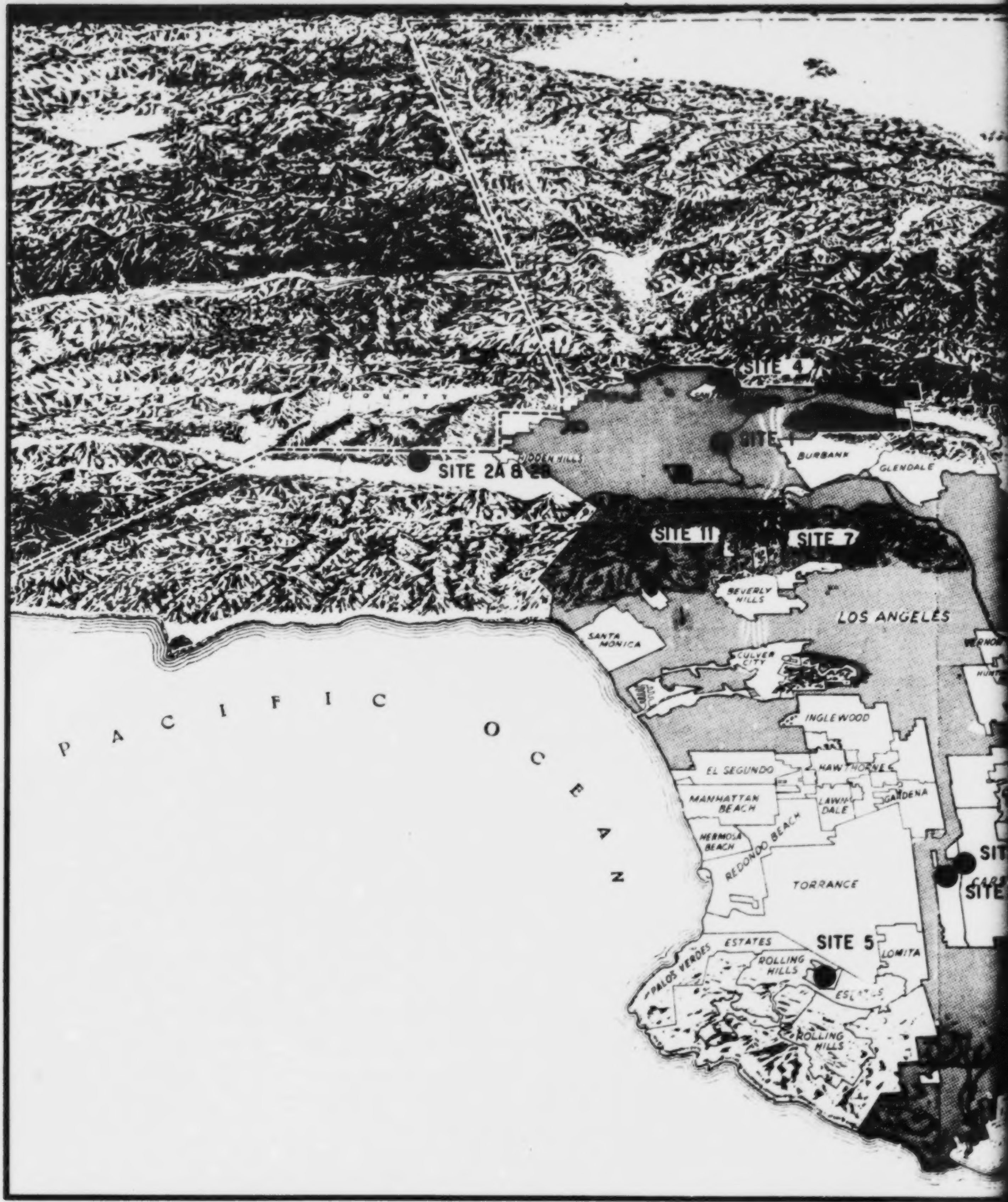
A soil sampling program was carried out around the selected landfills to obtain a better understanding of the nature of soil material around these landfills. This information was utilized, in part, to interpret the pattern of gas movement around each landfill and to provide a basis for making objective judgments as to the advantage of one site over another. The field investigation included the measurements of in-place density of the soils around the refuse sites and a visual survey of the soil pattern in the immediate vicinity of the fills.

PLATE A


MOJAVE DESERT
ANTELOPE VALLEY
SITE 4
SITE 1
SITE 2A & 2B
SITE 11
SITE 7
SITE 8
SITE 6
SITE 3
SITE 5
PACIFIC OCEAN
LOS ANGELES
SANTA MONICA
BEVERLY HILLS
BURBANK
GLENDALE
PASADENA
SOUTH PASADENA
SAN MARINO
ARCADIA
MONROVIA
TEMPLE CITY
ALHAMBRA
MONTEREY PARK
EL MONTE
WEST COVINA
POMONA
INDUSTRY
COMMERCE
MONTEBELLO
PICO RIVERA
WHITTIER
SANTA FE SPRINGS
DOWNEY
BELL
SOUTH GATE
LYNWOOD
COMPTON
PARAMOUNT
BELLFLOWER
NORWALK
LA MIRADA
ARTESIA
CERRITOS
LAKEWOOD
HAWAIIAN GARDENS
SIGNAL HILL
LONG BEACH
INGLEWOOD
EL SEGUNDO
MANHATTAN BEACH
HERMOSA BEACH
REDONDO BEACH
LAWNDALE
TORRANCE
LOMITA
ROLLING HILLS ESTATES
ROLLING HILLS
PALOS VERDES ESTATES

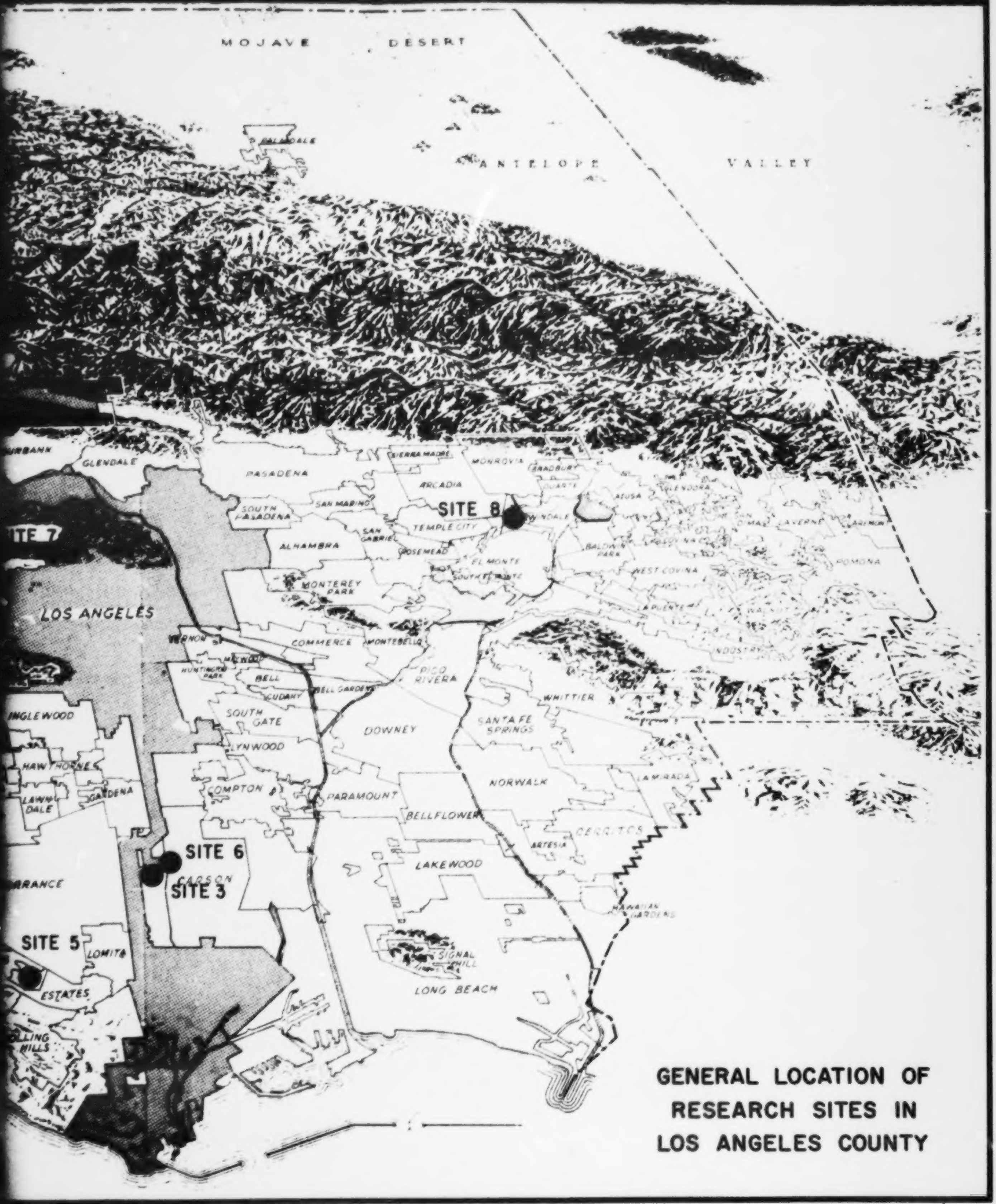
XXXXXXXXXXXXXXXXXXXXXXX
See the following pages
for greater detail.
XXXXXXXXXXXXXXXXXXXXXXX

GENERAL LOCATION OF
RESEARCH SITES IN
LOS ANGELES COUNTY


SITE 4
COUNTY
SITE 1
SITE 2A & 2B
HIDDEN HILLS
BURBANK
GLENDALE
SITE 11
SITE 7
BEVERLY HILLS
LOS ANGELES
SANTA MONICA
CULVER CITY
PACIFIC OCEAN
INGLEWOOD
EL SEGUNDO
HAWTHORNE
MANHATTAN BEACH
LAWNDALE
GARDENA
HERMOSA BEACH
REDONDO BEACH
TORRANCE
SITE 5
ESTATES
LOMITA
PALOS VERDES
ROLLING HILLS
ESTATES
ROLLING HILLS

A

PLATE A


MOJAVE DESERT
PALMDALE
ANTELOPE VALLEY
BURBANK
GLENDALE
PASADENA
SIERRA MADRE
MONROVIA
BRADBURY
DUARTE
ARCADIA
SOUTH PASADENA
SAN MARINO
SITE 8
TEMPLE CITY
AZUSA
GLENDORA
SAN GABRIEL
ALHAMBRA
ROSEMEAD
EL MONTE
SOUTH EL MONTE
BALDWIN PARK
WEST COVINA
POMONA
LA VERNE
MONTEREY PARK
LA PUENTE
WALNUT
INDUSTRY
LOS ANGELES
VERNON
MAYWOOD
COMMERCE
MONTEBELLO
HUNTINGTON PARK
BELL
CUDAHY
BELL GARDENS
PICO RIVERA
WHITTIER
INGLEWOOD
SOUTH GATE
DOWNEY
SANTA FE SPRINGS
LYNWOOD
HAWTHORNE
LAWNDALE
GARDENA
COMPTON
PARAMOUNT
NORWALK
LA MIRADA
BELLFLOWER
CERRITOS
ARTESIA
SITE 6
CARSON
SITE 3
LAKEWOOD
TORRANCE
HAWAIIAN GARDENS
SITE 5
LOMITA
ESTATES
SIGNAL HILL
LONG BEACH
ROLLING HILLS

GENERAL LOCATION OF RESEARCH SITES IN LOS ANGELES COUNTY

B

ENGINEERING – SCIENCE, INC.

TABLE III-1

SCOPE OF STUDY AT SELECTED LANDFILL SITES

Site No.	Number of Gas Analyses			Settlement Surveys		Soil Test
	1st Run	2nd Run	3rd Run	No. of Monuments	No. of Surveys	
1	67	59	--	--	--	Yes
2-A	19	12	18	--	--	Yes ***
2-B	--	--	--	14	2	No ****
3	34	27	--	24	2	Yes
4	49	40	--	54	2	Yes
5	44	22	--	57	2	Yes
6	54	46	--	--	--	Yes
7	10	8	--	3	3, 7, & 13 *	Yes
8	58	38	--	--	--	Yes
9	49	61	--	82	2	Yes
10	8	7	--	12	--	No ****
11	--	--	--	29	11 & 7 **	No ****

---

* Monument "Sterns" has had three surveys, "L" seven, and "SN" thirteen (Table III-8)

** 100 series monuments have had 11 surveys and 300 series monuments - 7 surveys (Table III-11)

*** By others

**** These sites were not used for lateral gas movement study

Laboratory tests on selected samples included the determination of specific gravity, porosity, and particle size distribution. Field density tests were taken in accordance with ASTM test method D 1556-64 (sand cone method). Values of soil characteristics for samples collected at the project landfill sites are shown in Table III-2. Specific gravity and mechanical analyses tests were made in accordance with ASTM test methods D 854-58 (1965) and D 422-63, respectively. The results of these tests are shown in Figures III-1 through III-5.

Soils obtained for testing were representative of the type of material throughout the site and in adjacent areas. A description of the soil types encountered at each site is presented as follows:

Site No. 1

The field density test was taken on the slope of a former gravel pit southwest of the completed landfill area. The soil in this area generally consists of gravelly sand with cobbles and small boulders. Large settlement cracks were noted on the surface of the landfill at the time of field investigation.

Site No. 2-A

This landfill is located in a steep ravine where compacted earth fill was constructed on private property across the canyon axis for the purpose of increasing site capacity. The landfill was constructed by a public agency and the earth fill was constructed from soil obtained at the site. Interest in gas movement at this site was directed toward the flow of gas outward through the earth fill where probes for gas sampling and analysis were placed. "Control of compacted fill" records indicate that soil was placed at an average of 93.1 percent of maximum density (mean, 93; max., 99; min., 87). A composite (4 sample) particle size distribution curve for this soil is shown in Figure III-1.

Site No. 3

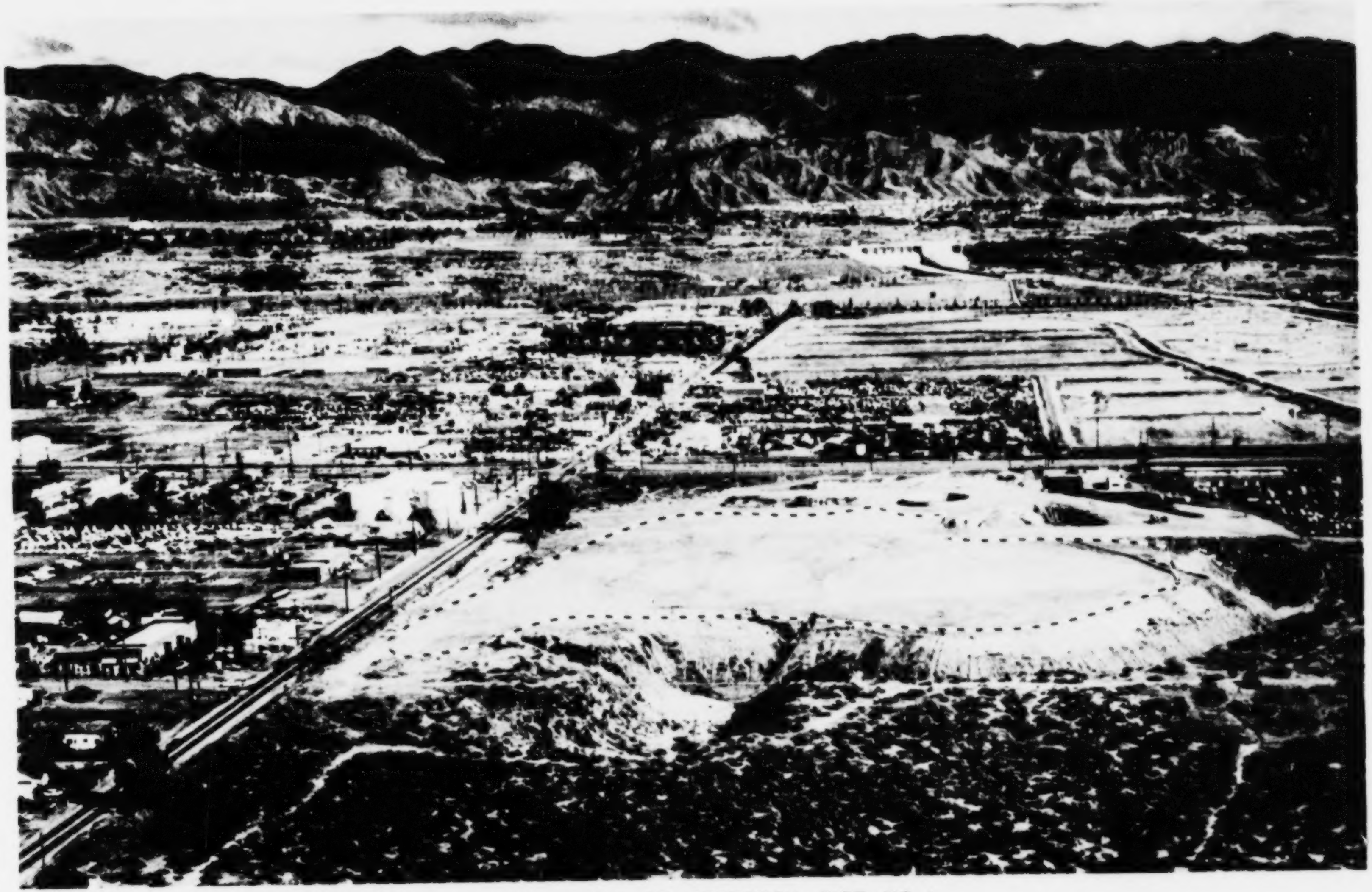
The soil tested in this area was located in a footing excavation for a proposed structure adjacent to the landfill and consisted of silty clay. Although there were only limited visual exposures of raw soil, the soil profile at this site appears to be similar to that of Site No. 6.

TABLE III-2

RESULTS OF SOIL ANALYSES FOR SELECTED LANDFILL SITES

Site No.	Material Description	Unified Soil Classification	Wet Density* (pcf)	Moisture Content (%)	Dry Density (pcf)	Porosity	Void Ratio
1	Gravelly Sand	SW	131.0	7.7	122.5	0.272	0.374
2-A	Silty Shale	--	101.2	22.6	94.2	--	--
3	Silty Clay	CL	128.5	11.1	115.5	0.294	0.416
4	Sandy Silt	ML	110.5	14.8	101.5	0.364	0.573
	Silty Sand	SM	118.5	7.3	110.5	0.332	0.497
5	Silty Clay (diatomaceous)	CL	51.5	16.0	44.4	0.704	2.38
	Silty Clay (diatomaceous)	CL	106.2	6.2	100.0	0.359	0.560
6	Sandy Silt	ML	137.5	19.6	115.0	0.300	0.429
	Silty Clay	CL	99.0	14.5	86.3	0.429	0.750
7	Gravelly Sand	SW-SM	111.5	7.8	103.5	0.382	0.618
8	Gravelly Sand with Silt	SM	114.5	4.4	109.5	0.346	0.530
9	Gravel-Sand and Silt Mixture	GW-GM	101.5	3.2	98.2	0.418	0.707

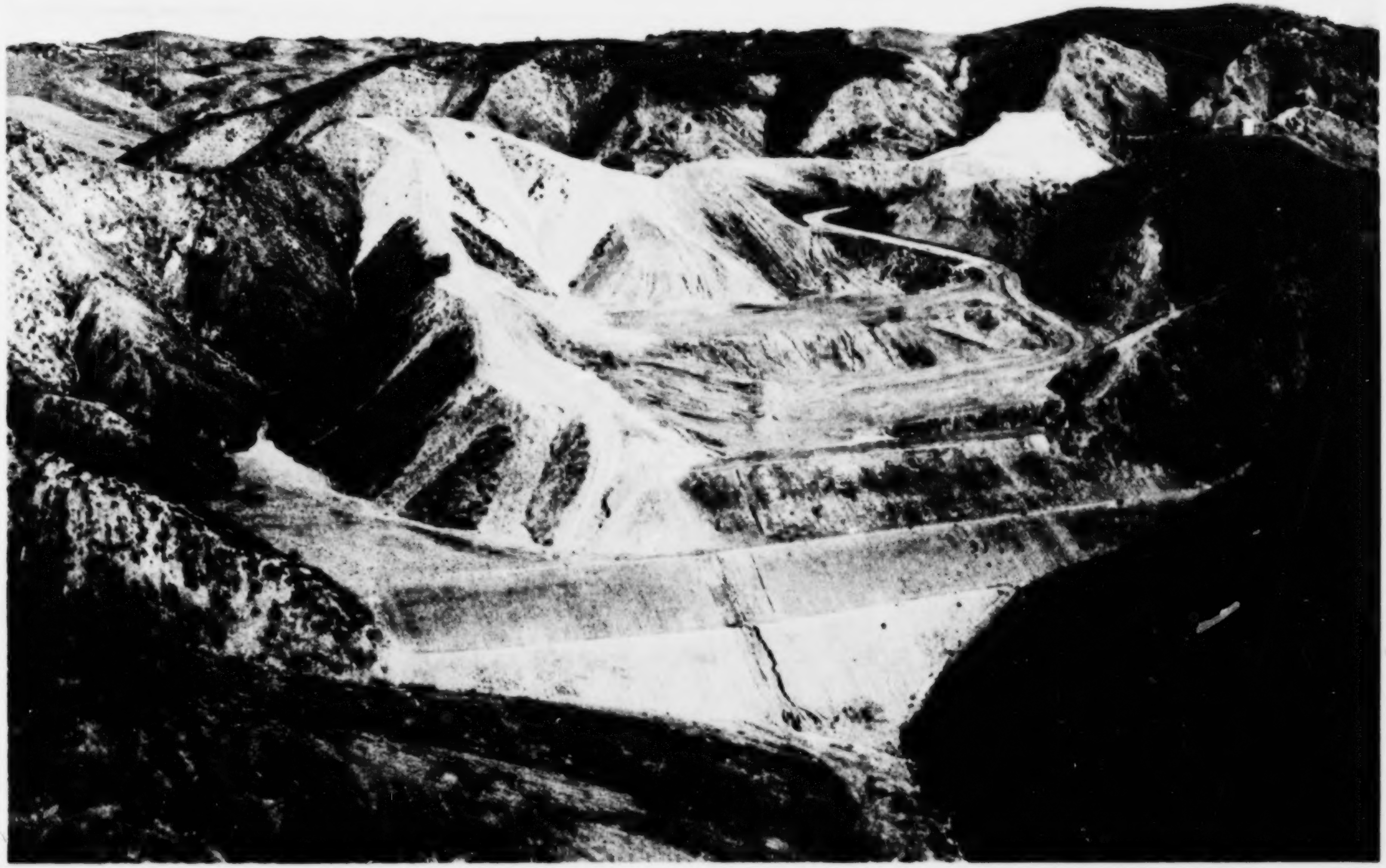
* In place



AERIAL VIEW OF RESEARCH SITE NO. 1

Limits of rubbish fill

PLATE C



AERIAL VIEW OF RESEARCH SITE NO 2-A

Site No. 4

Tests at this site were located south and east of the trailer park. The soils in the canyon which served as the refuse disposal site generally consist of interbedded sandstone, shale and siltstone. A large settlement crack was noted extending laterally across the face of the fill area.

Site No. 5

This area was formerly a diatomite quarry. Samples were taken on the south boundary of the site in soils containing a varying percentage of diatomite. The hill on the north boundary of the site is also composed of diatomaceous shale.

Site No. 6

The sample area was located at the north end of the site where excavation was underway for an additional refuse site. The alluvium in this area is composed of 15 to 20 feet of silty clay underlain by silty sands and sandy silts with an occasional 2 to 3 foot layer of silty clay. Tests were made in the silty clay and sandy silt soils.

Site No. 7

The in-place density test at this site was taken northeast of the fill area at the toe of the slope (at a horseshoe bend in the road). The soil generally consists of a gravelly and silty sand.

Site No. 8

The test at this site was taken on the slope of a former gravel pit, directly above a spreading basin. The soil consisted of gravelly sand with some silt. Large settlement cracks were noted on the road between the trailer park and the spreading basin. Soils in the area generally consist of gravelly sand with cobbles and small boulders.

Site No. 9

The density test was taken on the slope of a former gravel pit northeast of the completed sanitary landfill area. Soils in this area generally consist of silty sand and gravel.

GAS SAMPLING PROBE INSTALLATION

A program of probe installation and gas sampling was undertaken to measure gas concentrations in the soil atmosphere at various locations around the landfills selected for this study. The probes were made of 1/8-inch inside diameter (ID) plastic tubing with 1/16-inch wall thickness. The buried 6½-inch section of each probe was perforated and covered by a plastic tube of 3/8-inch ID, also perforated. The plastic tubes were heat-sealed and the assembly was covered with a piece of burlap cloth to prevent clogging of the perforations. Details of a single probe with gas sampling apparatus are shown schematically in Figure III-6 and a typical disassembled probe is shown in Figure III-7.

A majority of the probes installed were shallow, from 2 to 3 feet below the ground surface; however, a few were installed as deep as 8 feet below ground surface where additional information was required. Several types of equipment were used to install the probes, including hand augers, a power driven auger, a pneumatic rock drill and a special device fitted to a dozer ripper. The actual equipment used at each site was determined by conditions encountered. Various phases of probe installation are shown in Figures III-8, III-9 and III-10.

At sites No. 1 and 8, sewer manholes were used to place gas probes into the soil at various depths. With the cooperation of the operating public agency, holes were drilled through the manhole wall and probes were inserted into the soil surrounding the manhole. The holes were sealed with grout to insure that gas samples were drawn from the soil atmosphere. A typical gas probe installed through the wall of a sewer manhole is shown in Figure III-11.

The work program for probe installation is presented in detail as follows:

Site No. 1

A total of 63 probes were installed as shown in Figure III-12. In addition to shallow probes installed in the ground adjacent to the landfill, nine probes were installed through the wall of sewer manholes located in an adjacent street. Three probes each were installed in three manholes at depths of 2, 6 and 16 feet to determine variations of gas concentration with depth.

The installation of probes at this site proved to be very difficult because the type of material (gravel and rocks of varying sizes) necessitated the digging of large holes to install some of the probes. For these probe installations, a rapid cure asphalt material (RC-1) was sprayed over the backfill material and side walls of the excavations to seal these surfaces against atmospheric contact and to eliminate possible contamination of gas samples. Four additional probes, previously installed in a 25 feet deep well by a public agency, were also used at this site.

Site No. 2-A

Nineteen probes were installed at this site by others prior to the start of this project. The location of these probes is shown in Figure III-14.

Site No. 3

A total of 35 probes were installed as shown in Figure III-17.

Site No. 4

A total of 49 probes were installed as shown in Figure III-19.

Site No. 5

Twenty-five new probes were installed as shown in Figure III-21. In addition to taking samples from the new probes, samples were also taken from approximately 19 probes previously installed at this site by a public agency.

Site No. 6

A total of 47 probes were installed as shown in Figure III-22.

Site No. 7

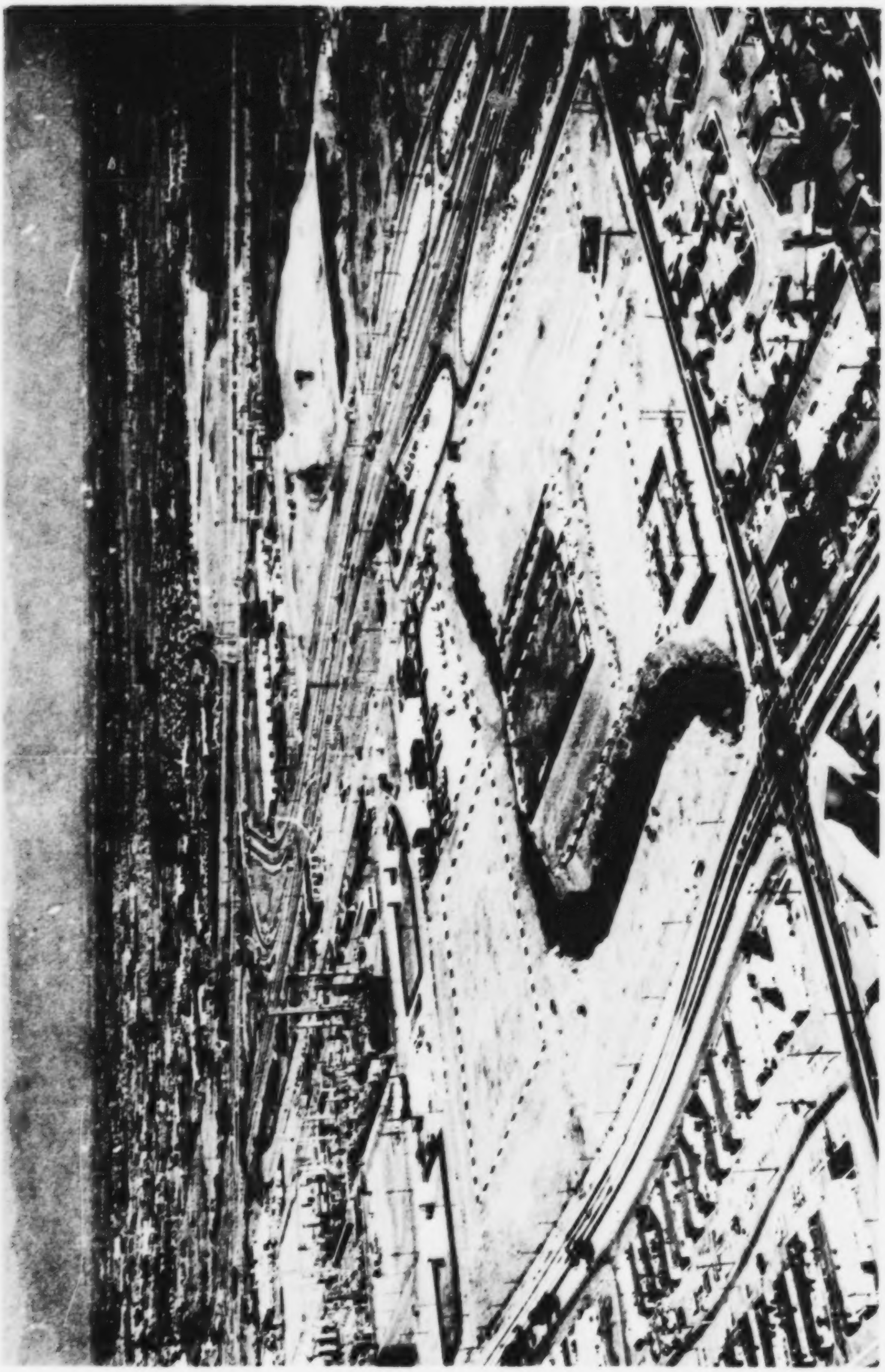
A total of 10 probes were installed as shown in Figure III-23. Due to the hilly topography of this area, detailed gas movement studies were not undertaken at this site.

Site No. 8

A total of 37 probes were installed as shown in Figure III-24. This figure also shows the location of 8 probes that originally existed at this site.

PLATE D

AERIAL VIEW OF RESEARCH SITE NO 2-B



AERIAL VIEW OF RESEARCH SITE NO. 3
Limits of rubbish fill

Site No. 9

A total of 64 probes were installed as shown in Figure III-26. Sampling of the probes and analysis of the samples were performed by the personnel of the operating public agency.

Site No. 10

A total of 8 probes were installed at this site to obtain experimental data on the composition of gases generated in a landfill which is subject to seawater intrusion. These probes were installed on four sections of the landfill which had been completed from 3 to 30 years. The location of these probes are shown in Figure III-37.

GAS SAMPLING PROCEDURE

In order to sample the large number of gas probes installed for this study it was necessary to devise a sampling method (Figure III-6) which was both fast and reliable.

The selected sampling method was based on the principle of displacing air in the sampling bottle by gases existing in the soil at the level of the probe. In order to achieve this objective, the air in the sampling bottle could have been removed by either liquid displacement or by use of a vacuum pump. Liquid displacement represented a reliable method for sampling the gas probes, but it proved to be excessively time consuming. The majority of sampling bottles were, therefore, connected to a vacuum pump in the laboratory and approximately 97 percent of the air was removed. The bottle stop cocks were lubricated to make them gas tight in order to preserve the vacuum during travel from laboratory to probe locations in the field. To sample each probe, the gas contained in the probe and its lead was evacuated by the use of a hand aspirator. The number of necessary pumps of the aspirator to completely evacuate the full length of the probe was calculated to insure obtaining a representative sample. The probe was then connected to the sampling bottle and the gas was allowed to fill the vacuum generated in the bottle. This method proved to be reliable and economical.

One of the first steps of the study was to evaluate the sampling procedures to insure reliability and maximize accuracy of results. Two items of concern relative to gas collection procedures were (1) the effects of under evacuation and over evacuation of the probe and probe lead and (2) the point at which a steady state condition is reached when successive samples are collected from the same probe. Site No. 2A was selected for a test and the procedure consisted of: (1) collecting four successive 120 milliliter (ml) samples from each of three probes; (2) evacuating approximately 380 ml from the probe by means of a hand aspirator, and (3) collecting six successive 120 ml samples from each of two probes.

Gas samples were collected over acidified water and test results indicated that over evacuation of the theoretical volume of the probe and its lead did not effect the steady state condition of gas concentration through the tested ranges. The steady state condition occurred after about 360 ml of gas had been evacuated from the probe.

The conclusions of this analysis were that the cap placed over the probe lead end was not air tight, that the gas sample taken from the probe initially was not representative of true concentration of gases in the surrounding soil and that, to maximize the accuracy of results, at least 360 ml of gas must be evacuated from the probe prior to collecting the sample. A recommended gas collection assembly to achieve this purpose is shown in Figure III-6. It should be noted that the gas collection bottle is connected ahead of the aspirator to minimize the possibility of contamination as a result of connecting and disconnecting the gas collection bottle.

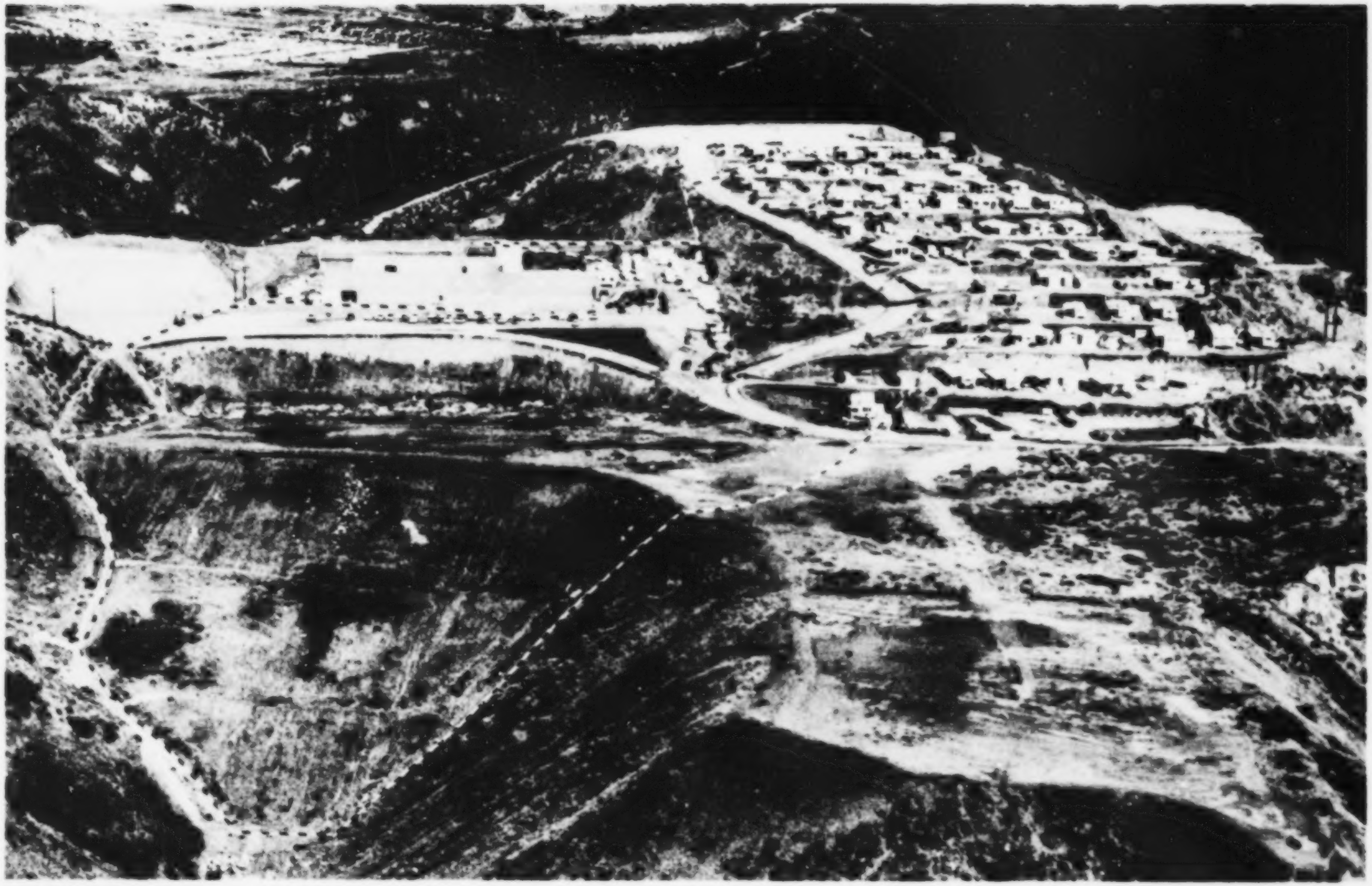
GAS ANALYSIS

Three sets of gas samples were collected and analyzed from Site No. 2-A and two sets of samples were collected and analyzed from Site No.'s 1, 3, 4, 5, 6, 7, 8, 9 and 10. The complete results of these analyses are presented in Appendix C. Concentrations of carbon dioxide (CO_2), oxygen (O_2), nitrogen (N_2) and methane (CH_4) are shown as percentages by volume of total gas present. Concentrations of hydrogen sulfide (H_2S) are also shown for Site No. 10.

A more detailed description of results at each site follows:

Site No. 1

A plot of methane concentration contours, derived from the results of the analyses is shown in Figures III-12 and III-13. From these plots it



AERIAL VIEW OF RESEARCH SITE NO. 4
Limits of rubbish fill

is apparent that gas is moving a considerable distance into the surrounding area from this fill. The extensive movement of gases from this landfill has prompted the establishment of a barrier or control device for reducing this gas movement. Details of the design of the experimental control system for this site are presented in Chapter V.

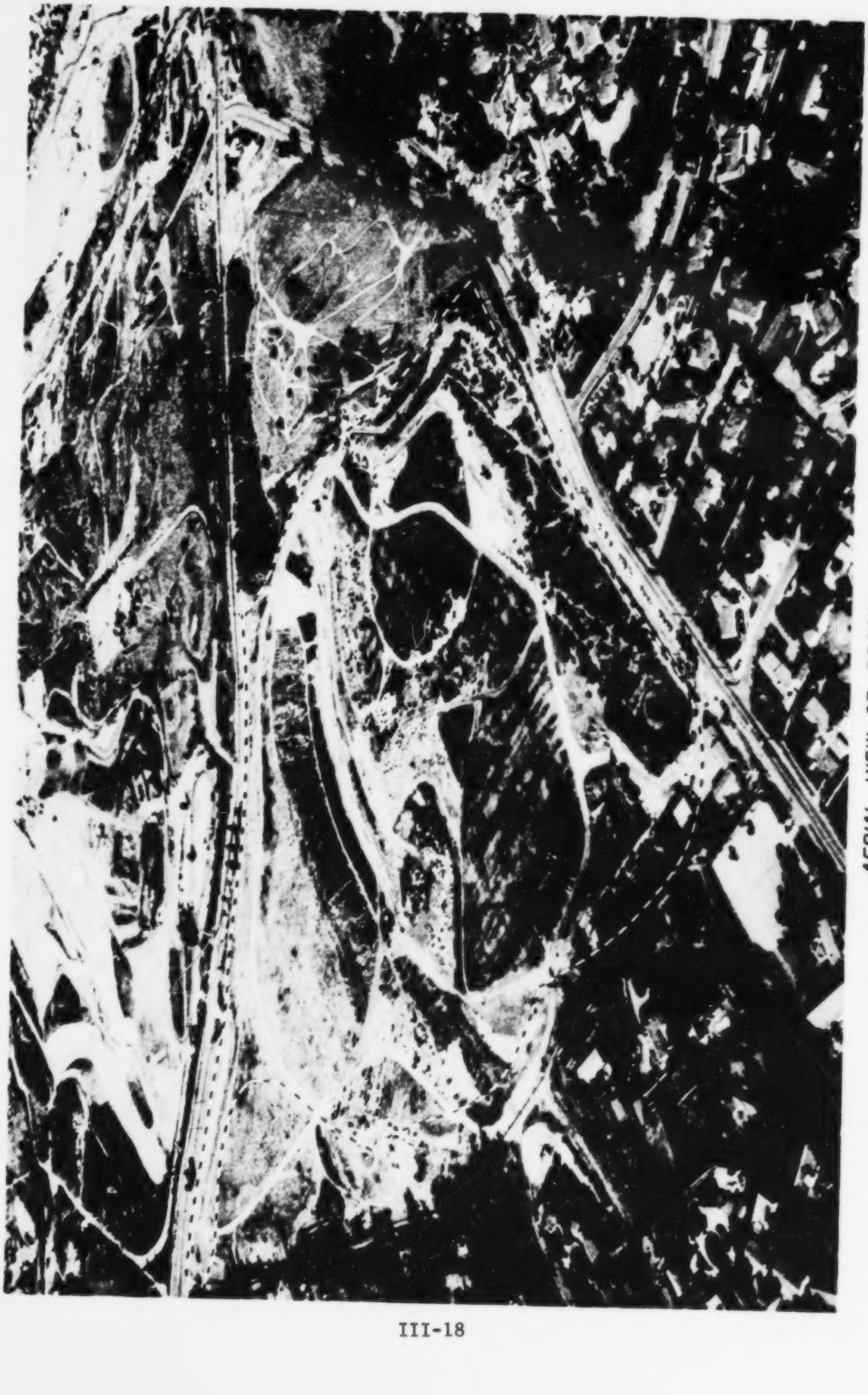
Site No. 2-A

The first analysis indicated the early presence of CO_2 in large quantities while there was little indication of the presence of methane. This lack of methane was probably due to the newness of the fill in that the microbial population which produces methane had not yet established itself to an appreciable degree. Later analyses have indicated small amounts of methane.

Contours of CO_2 concentration from the first analysis (Figure III-14) indicated a possible anomaly in that CO_2 concentration decreased normally with distance from the face of the landfill up to a certain point where it showed an unexpected increase. Extreme care was exercised during the second collection and analysis so that possible errors in sampling and analysis technique would be minimized. However, as evidenced by CO_2 contours (Figures III-15 and III-16) the same anomaly existed during the second and third sampling operations. One possible reason for this anomaly is that the fill material contained organic or chemical material which is liberating CO_2 upon exposure to moisture so that CO_2 concentrations are more a function of the distance from free dam surface (and surface moisture) than a function of distance from landfill material. It is assumed from the contour symmetry that CO_2 from the landfill is not entering the dam in significant quantities.

Site No. 3

Contours of methane concentration at this site are shown in Figures III-17 and III-18. Present foci of high production are clearly identified. Concentration levels at the north portion have increased approximately 30 percent in a 6 month period while concentrations at the south have increased only slightly. Methane is penetrating significantly to the east at the southeasterly fill boundary.



AERIAL VIEW OF RESEARCH SITE NO. 5

Limits of rubbish fill

Site No. 4

Gas sampling and analysis was carried out at this site and plots of apparent methane concentration contours derived from the results of the analyses are shown in Figures III-19 and III-20. The fact that gases are being allowed to vent to the surface through the many cracks and fissures in the surface over and adjacent to the landfill contributes greatly to the erratic contour pattern shown. Also, the many gas-venting "Tiki" burners installed at the site could have some bearing on gas concentrations. The location of major surface cracks is shown on the methane contour figures, as is the location of burners.

Site No. 5

Results of the analyses of the samples taken from this site are inconclusive and no definite pattern of gas movement can be established. It is evident, however, that a barrier gravel trench, installed by a public agency (Chapter V), is allowing gas to vent, thus reducing gas movement into adjoining properties.

Site No. 6

This landfill site had a total of 47 probes installed at regular intervals along the western side of the fill area. Results of the first collection and analysis showed extremely irregular concentrations. The second gas sampling, performed eight months later, yielded more consistent data which resulted in the plotting of contours of relatively high methane concentrations as shown in Figure III-22.

The lack of consistency could be explained by the fact that analyses from those first sampling probes which showed extremely low concentrations of methane were performed only 11 days following probe installation. This period was apparently insufficient to allow the soil atmosphere to come into equilibrium with the gases moving from the landfill under normal conditions. Further sampling will be performed and the results will be reported in the second annual report.

Site No. 7

Results are nonconclusive and, because the number of probes was limited, no definite pattern of gas movement could be established for this landfill.

PLATE H

AERIAL VIEW OF RESEARCH SITE NO 6

Limits of completed rubbish fill

Site No. 8

Gas analyses at this site showed methane concentrations as high as 10 percent exist at a distance of 600 feet from the fill. This can be attributed to the gravelly nature of soil formations around this landfill. Contours of methane concentration from analyses made 5 months apart (Figures III-24 and III-25) indicate little change of concentration with time.

Site No. 9

Contours of methane concentration from two gas analyses, performed 4 months apart, are shown in Figures III-26 and III-27. Results indicate little change at the eastern end of the landfill; concentrations increased approximately 20 percent at the western end. It is apparent that a shallow surface crack, existing at the landfill interface is venting some surface methane to the atmosphere as surface methane concentrations show a rise in value prior to falling when correlated with their distance from the landfill.

Site No. 10

Two sets of samples were obtained from the eight probes at this site and were analyzed. A trace of hydrogen sulfide was found in all of these samples. The presence of this normally foreign gas can be attributed in part to the existence of salt water in the fill. Another point of interest is that significant quantities of gas are still being generated in those parts of the fill that are more than 30 years old. Probes No. 1 and 2 (Figure III-37) were installed in the old part of the landfill.

SANITARY LANDFILL SUBSIDENCE

Differential settlement of the surface of completed sanitary landfills presents a serious problem in the design of surface and subsurface structures and thereby greatly inhibits the unrestricted use of the completed site. Settlement estimates and possible methods of control are to be reviewed during the second year of the total study; however, data gathered during the first year is presented in this report.

The potential magnitude of the settlement problem is shown in Figure III-28. Damage of this sort and of this magnitude is common for rigid

PLATE J

AERIAL VIEW OF RESEARCH SITE NO. 7

structures not designed to withstand differential settlement; and flexible pavements invariably fail when subjected to subgrade settlement.

Monuments were established and surveying was carried out on sites where the condition of the site was such that no major physical alterations were expected during the three years of the study program. Survey data was further collected on other sites where monuments had been previously established and where previous levels had been made and were of record.

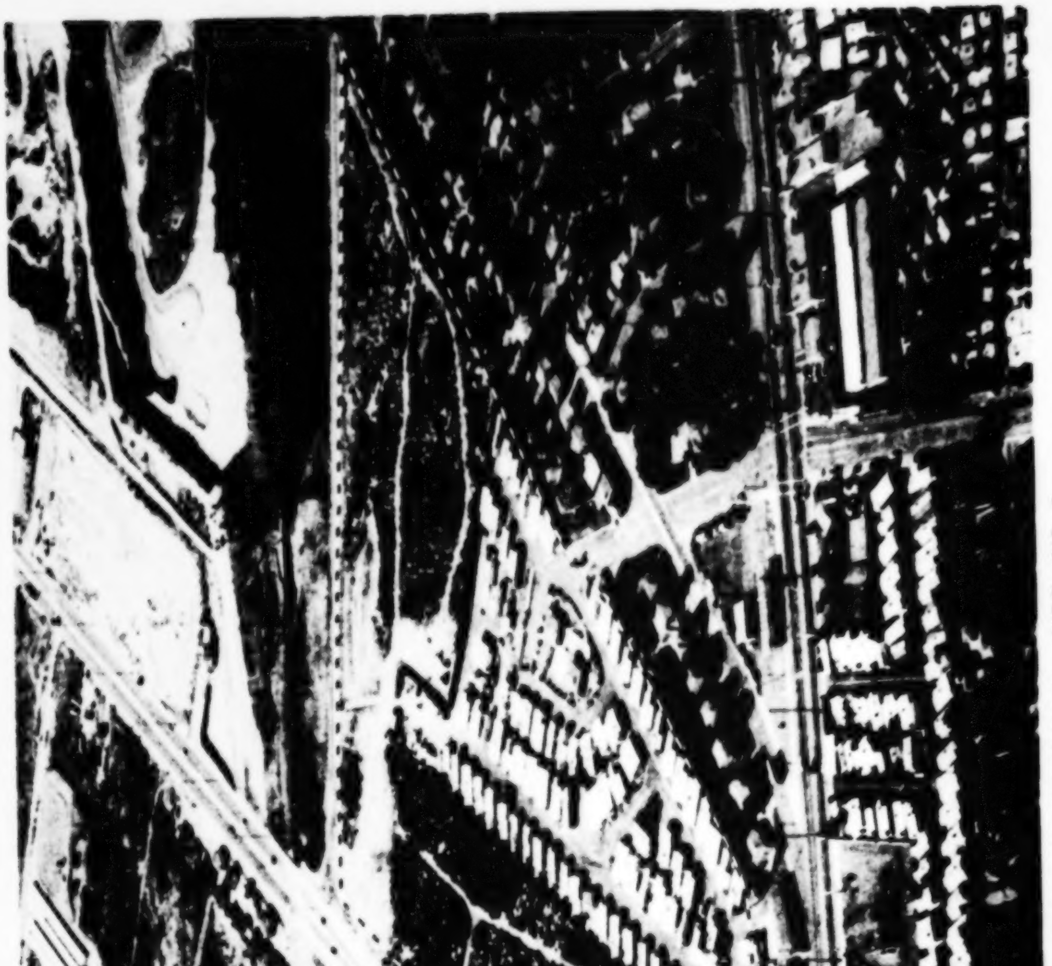
A summary of settlement survey data for selected sites follows:

Site No. 2-B

This landfill site is operated by a public agency. Portions of the fill have been completed and a series of monuments and control points along two profile lines have been established on one of the completed areas. The profile lines traverse the fill area in two directions and are approximately at right angles to each other. One profile line (approximately 730 feet long) has nine monuments; the other line, approximately 350 feet long, has five monuments. Each monument is a standard Los Angeles County Engineer concrete bench mark and has been so set that both vertical and lateral movements can be determined. Two sets of levels have been taken and settlements are shown in Table III-3. Monument locations are shown in Figure III-29 and are further indicated on a photograph in Figure III-30.

Site No. 3

This landfill was privately constructed. It is located in a low slough area and was completed in 1962. A portion of the site consists of a planted and irrigated soccer field, four small service buildings, and a fairly large parking area surfaced with asphaltic material. Construction was completed in 1967. Two survey lines were established at this site. Each line traverses the soccer field area, in slightly different directions, to determine the effect of irrigation on the rate of settlement. Each profile line was established with control monuments at each end of the line and one-inch diameter iron pipes were set at approximately 100 foot inter-



AERIAL VIEW OF RESEARCH SITE NO. 8

Limits of rubbish fill

TABLE III-3

SETTLEMENT RECORD AT SITE NO. 2-B

Monument	Elevation 22 June 1967	Elevation 11 Dec. 1967	Settlement (ft.)	Lateral Movement (ft) North	Lateral Movement (ft) East
CL 1	1078.80	1078.80	0	0.01	-0.01
CL 2	1139.07	1138.71	0.36	0.10	0.13
CL 3	1141.53	1141.21	0.32	0.10	0.08
CL 4	1143.32	1143.05	0.27	0.10	0.07
CL 5	1143.98	1143.70	0.28	0.09	0.07
CL 6	1145.88	1145.55	0.33	0.06	0.06
CL 7	1145.97	1145.57	0.40	0.01	0.06
CL 8	1147.05	1146.68	0.37	-0.01	0.07
CL 9	1180.06	---	--	-0.03	-0.01
CL 10	1138.24	1138.01	0.23	0.09	0.18
CL 11	1134.76	1134.66	0.10	0.03	0.12
CL 12	1131.15	1131.02	0.13	0.02	0.12
CL 13	1128.81	1128.75	0.06	0.03	0.07
CL 14	1126.98	1126.98	0	-0.01	0.03

vals. One of the lines is 800 feet long and the other is approximately 1,000 feet long. In addition to the profile lines, seven elevation points have been established on the concrete floor slabs of the buildings. Elevations of all established points have been taken twice and settlement values are presented in Table III-4. Monument locations are shown in Figure III-31.

Site No. 4

This canyon landfill was privately constructed and completed in 1961. It is a very deep landfill and has experienced a substantial amount of settlement since completion. A trailer park and a trailer manufacturing company have been constructed on natural ground areas adjacent to the fill. Both installations have constructed sewage

TABLE III-4

SETTLEMENT RECORD AT SITE NO. 3

Station	Elevation 3 Aug. 1967	Elevation 29 Jan. 1968	*Change in Elevation(ft) +	-
Line A:				
1 + 00	29.37	29.26		0.11
2 + 00	30.23	30.11		0.12
3 + 00	29.54	29.55	0.01	
4 + 00	29.42	29.36		0.06
5 + 00	29.78	29.69		0.09
5 + 61	31.04	31.05	0.01	
5 + 86.7	30.7	30.8	0.10	
6 + 00	30.5	30.5	0	0
7 + 00	30.0	29.9		0.10
7 + 90.6	30.1	30.1	0	0
8 + 00	30.0	30.0	0	0
9 + 00	29.6	29.7	0.10	
10 + 10.1	29.31	29.30		0.01
Line B:				
1 + 00	28.17	28.22	0.05	
2 + 00	29.24	29.20		0.04
3 + 00	29.96	29.92		0.04
3 + 51.5	30.13	30.03		0.10
4 + 00	30.15	30.14		0.01
4 + 54	30.76	30.70		0.06
5 + 00	30.4	30.7	0.3	
6 + 00	30.3	30.2		0.1
7 + 00	29.6	29.6	0	0
8 + 00	29.1	29.0		0.1
8 + 14.8	28.49	28.32		0.17

(Table continued on next page)

* Plus changes in elevation to be verified by continuing study.

TABLE III-4 (Continued)

SETTLEMENT RECORD AT SITE NO. 3

Station	Elevation 3 Aug. 1967	Elevation 29 Jan. 1968	Change in Elevation(ft) +	-
Floor H.T. DR	30.28	30.13		0.15
Floor V.T. DR	30.39	30.27		0.12
Floor Off. DR	30.83	30.81		0.02
Floor L. RM	30.86	30.85		0.01
Floor S.B.	30.86	30.76		0.10
Slab S.B. (NW)	30.85	30.80		0.05
Slab S.B. (NE)	30.51	30.34		0.17

collection facilities and leaching fields over the rubbish fill. This saturation of the fill with sewage has accelerated decomposition, resulting in considerable settlement in the leaching area.

Three survey lines have been established at the site. The main base line, approximately 1,408 feet long, runs the length of the fill through the area of greatest settlement. Control monuments have been set at each end of the line on firm natural soil. A second line, approximately at right angles to the main line, traverses the width of the fill area and is approximately 485 feet long. Elevations have been taken twice on points along these two lines and a summary of the changes in elevation is shown in Table III-5. The third line is approximately 635 feet long and was established southerly of the built up area, again traversing the width of the fill. To date, elevations along this third line have been taken only once. Monument locations at this site are shown in Figure III-32.

Site No. 5

This landfill was constructed by a public agency. It is a completed site, constructed and designed with the intention that, after the completion of filling operations, it be used as the site for a botanic garden. Upon completion of filling operations, the site was surveyed and a grid of

TABLE III-5

SETTLEMENT RECORD AT SITE NO. 4

Station	Elevation 1 Aug. 1967	Elevation 11 Dec. 1967	*Change in Elevation(ft)	
			+	-
Line A:				
0 + 00	1000.00	1000.00	Assumed Elevation	
0 + 38	1000.6	1000.3		0.3
0 + 48.5	1001.02	1001.06	0.04	
0 + 86.1	1002.57	1002.54		0.03
1 + 11.5	1001.7	1001.7	0	0
1 + 94	1004.6	1005.1	0.5	
2 + 05	1009.87	1009.65		0.22
2 + 39	1010.62	1009.37		1.25
2 + 70	1014.67	1013.64		1.03
3 + 19	1015.15	1014.35		0.80
3 + 53	1021.89	---	--	--
3 + 68	1027.0	1026.0		1.0
3 + 83.81	1027.34	1026.77		0.57
3 + 85.64	---	1026.64	--	--
4 + 47.6	1024.5	1023.6		0.9
5 + 29.79	1026.95	1026.04		0.91
6 + 07.8	1030.5	1029.7		0.8
6 + 10.8	1030.45	---	--	--
6 + 95	1029.9	1029.6		0.3
7 + 63.5	---	1033.1	--	--
7 + 71.5	---	1034.9	--	--
7 + 95	1036.8	---	--	--
8 + 41	---	1038.5	--	--
8 + 51.8	1038.8	---	--	--
10 + 33.69	1080.3	1081.0	0.7	
Line 4-E:				
0 + 00	1026.95	1026.04		0.91
0 + 49.8	1024.5	1023.8		0.7
1 + 21.7	1027.22	1026.71		0.51
1 + 40.8	1030.3	1029.5		0.8
1 + 69.8	1034.17	1033.74		0.43
1 + 85	1038.3	1037.6		0.7
2 + 35	1043.9	1043.8		0.1
3 + 43.4	1044.78	1044.78	0	0
Line 4-W:				
0 + 00	1026.95	1026.04		0.91
0 + 24	1030.80	1029.64		1.16
0 + 53.5	1034.43	1033.49		0.94
0 + 79.7	1035.63	1034.89		0.74
1 + 05	1036.74	1036.67		0.07
1 + 41.3	1037.33	1037.34	0.01	
TBM	1042.59	1042.60	0.01	

Line No. 1 South - Elevations taken only once

---

* Plus changes in elevation to be verified by continuing study.

monuments was established for future construction control. A line of these monuments has been reestablished to be used as a base line for establishing two new profiles which traverse the site at right angles to the base line. These profile lines also utilized other previously established control monuments for monitoring lateral movement as well as vertical settlement. Temporary monuments were set along the base line and along the two profile lines at approximately 100 feet intervals or at points of abrupt change in profile. Monument locations are shown in Figure III-33 and the survey control system is further shown in Figure III-34, superimposed on a photograph.

The base line is 1,815 feet long and incorporates seven standard County Engineer monuments, which will be used for monitoring vertical and lateral changes. The other two profile lines are approximately 2,600 feet and 1,800 feet long. Each line has one base monument for measuring lateral movement. To date, elevations of all points have been taken twice and settlements at monument locations are shown in Table III-6.

TABLE III-6

SETTLEMENT RECORD AT SITE NO. 5

Monument	Elevation 27 April 1965	Elevation 30 June 1967	Elevation 30 Jan. 1968	Total Settlement (ft)
Base Line:				
N4312.07/E4000	--	378.861	378.861	0
N4300/E4000	--	378.312	378.312	0
N4100/E4000		360.178	360.080	0.098
N4095/E4000		360.351	360.220	0.131
N4000/E4000	364.02	362.865	362.467	1.553
N3900/E4000		374.418	374.180	0.238
N3800/E4000		385.493	385.367	0.126
N3700/E4000		390.198	390.039	0.159
N3600/E4000		392.207	392.071	0.136
N3500/E4000		393.028	392.821	0.207
N3400/E4000		393.242	393.165	0.077
N3300/E4000		390.196	390.080	0.116
N3200/E4000		384.212	383.982	0.230
N3100/E4000		380.412	380.223	0.189
N3000/E4000	381.58	380.827	380.694	0.886
N2900/E4000		386.031	386.934	0.097
N2800/E4000		388.272	388.208	0.064

TABLE III-6 (Continued)

SETTLEMENT RECORD AT SITE NO. 5

Monument	Elevation 27 April 1965	Elevation 30 June 1967	Elevation 30 Jan. 1968	Total Settlement (ft)
Base Line:				
N2773.60/E4000		387.758	387.672	0.086
N2700/E4000		385.850	385.634	0.216
N2600/E4000		388.309	388.160	0.149
Line A:				
N3000/E2600		412.937	411.509	0.428
N3000/E2900		406.186	406.124	0.062
N3000/E3000	388.89	388.536	388.497	0.393
N3000/E3100		372.646	372.624	0.022
N3000/E3200		351.132	351.128	0.004
N3000/E3300		343.173	343.165	0.008
N3000/E3400		355.885	355.490	0.395
N3000/E3500	361.39	361.335	361.328	0.062
N3000/E3600		369.956	369.879	0.077
N3000/E3700		371.770	371.705	0.065
N3000/E3800	--	378.885	378.828	0.057
N3000/E3900	--	384.266	384.132	0.134
N3000/E4100		384.064	383.997	0.067
N3000/E4200		384.069	383.975	0.094
N3000/E4300		364.681	364.395	0.286
Line B:				
N3500/E2016		409.818	409.80	0.018
N3500/E2121		409.389	409.343	0.046
N3500/E2306		408.855	408.82	0.035
N3500/E2500		410.835	410.825	0.010
N3500/E2666		408.553	408.48	0.073
N3500/E2815		399.403	399.30	0.103
N3500/E3000		387.496	387.33	0.166
N3500/E3120		380.308	380.16	0.148
N3500/E3257		343.232	343.00	0.232
N3500/E3447		345.725	345.21	0.515
N3500/E3500	357.51	355.969	355.64	0.329
N3500/E3600		371.010	370.815	0.195
N3500/E3700		379.507	379.29	0.217
N3500/E3800		386.935	386.70	0.235
N3500/E3900		391.241	391.04	0.201
N3500/E4100		392.806	392.58	0.226
N3500/E4200		390.893	390.65	0.243
N3500/E4300		386.571	386.412	0.159
N3500/E4400		382.527	382.39	0.137
N3500/E4500		372.793	372.72	0.073
N3500/E4600		342.385	342.38	0.005
N3500/E4635		333.579	333.571	0.008

Additional settlement data is available for this site through the public agency which constructed the landfill. These data were obtained by monitoring 21 monuments which were established shortly after the fill was completed. These monuments have been checked for changes in elevation for a period of three years at three to six month intervals. This information is valuable because of the relatively long period of time covered and the fact that each point is correlated to the depth of fill at that location. A summary of the total settlement for each point through October 1966 is shown in Table III-7.

TABLE III-7

CUMULATIVE THREE-YEAR SETTLEMENT RECORD AT SITE NO. 5

Monument No.	Depth of Fill (ft)	Total Settlement
101	80	0.52
102	80	1.09
103	100	0.73
104	90	0.29
105	95	0.70
106	120	1.31
107	130	3.06
108	130	0.94
109	95	0.89
110	95	1.07
111	115	0.73
112	125	1.22
113	120	0.63
114	95	0.72
115	85	--
116	90	1.87
117	90	1.87
118	75	2.25
119	70	1.52
120	85	2.12
121	46	1.26

Site No. 7

This landfill is also being constructed and operated by a public agency. No specific program was set up for the present study of settlement rates at this site because most of the area is still being used and those portions of the landfill which have been completed were not suitable for establishing a satisfactory system of monuments or would not be available for the full period of study. However, the agency operating the fill had previously established random monuments upon completed portions of the fill which were checked for elevation and lateral movement on a yearly basis. One of the monuments was checked for elevation change more frequently because it was located in an area upon which earth cover material had been stockpiled, and correlation between settlement and superimposed loading was being sought. These monuments will continue to be checked and the data will be incorporated in the settlement study as part of the second year program work.

A summary of the cumulative settlement and lateral displacement for these monuments through June 1966 is presented in Table III-8.

TABLE III-8

CUMULATIVE SETTLEMENT AND LATERAL MOVEMENT RECORD AT SITE NO. 7

Monument Designation and Date Established	Depth of Fill (ft)	Settlement (ft)	Lateral Movement (ft) Easterly	Lateral Movement (ft) Northerly
"Sterns" (Oct. 1964)	285	12.50	0.615	1.042
"L" (Aug. 1960)	70	2.59	1.12	-0.49
"SN" (Dec. 1963)	180	22.42	N.A.	N.A.

It should be noted that for monument "SN," stockpiling of earth cover material adjacent to the monument began in January 1965; the cumulative settlement through October 1964 was 10.97 feet. On 19 May 1965, after stockpiling had begun, the cumulative settlement was 16.43; on 23 June 1966, with the stockpile being approximately 10 feet deep, 150 feet wide, and 700 feet long the cumulative settlement was 22.42 feet. A map showing location of monuments appears as Figure III-35. Monument "L" is off the map area and could not be shown.

TABLE III-9

SETTLEMENT DATA AT SITE NO. 9

(Grid System Layout)

SETTLEMENT IN FEET

North	0+00	1+00	2+00	3+00	4+00	5+00	6+00	6+47	6+50	6+51	6+60	6+73	7+00	8+00	North Grid
East															
0+00	2.6	1.9	1.3	1.6	2.2	0.6	0.6	--	--	--	--	--	0.0	--	
1+00	3.4	2.1	2.4	2.1	2.2	2.0	1.4	--	--	--	--	--	1.9	1.4	
2+00	3.2	2.4	2.3	2.2	2.3	1.8	0.8	--	--	--	--	--	1.7	1.5	
3+00	--	1.5	1.7	2.0	2.3	1.5	1.4	--	--	--	--	--	1.6	1.7	
4+00	--	0.1	0.4	0.6	1.8	1.9	2.2	--	--	--	--	--	1.7	0.9	
4+47	--	--	+0.3	0.8	1.1	0.9	1.5	--	--	--	--	--	1.2	--	
4+56	--	--	--	--	2.7	--	--	--	--	--	--	--	--	--	
5+00	--	--	2+07 0.6	2.0	2.1	2.0	2.1	--	--	--	--	2.0	--	--	
6+00	--	--	2+23 0.7	2.2	2.2	2.0	1.7	--	--	2.6	--	--	--	--	
7+00	--	--	2+36 0.7	1.9	1.7	1.9	1.7	1.7	--	--	--	--	--	--	
8+00	--	--	2+52 0.9	1.2	1.3	1.4	1.8	--	1.4						
9+00	--	--	2+68 1.1	1.0	0.9	1.1	1.8	--	--	--	1.8				
9+48							1.5								
9+57						0.3									
9+64					0.7										
East Grid															

Note: See Figure III-36 for Grid Layout
First Elevations were taken in September 1966
Second Elevations were taken in September 1967

Site No. 9

The landfill at Site No. 9 was constructed under the guidance of a public agency. Upon completion of this fill, a grid system of profile lines, spaced 100 feet in each direction, was established to keep a continuing record of settlement. With the cooperation of the public agency, elevations at each grid point has been and will continue to be taken periodically and will be correlated with related data. Settlement results from two surveys is presented in Table III-9. Monument locations are shown in Figure III-36.

Site No. 10

This landfill is operated by a private agency and was constructed by erecting a levee around low-lying land adjacent to San Francisco Bay. Landfilling at this site has been continuing since 1945. Various types of commercial, residential and industrial solid wastes are disposed of at this site using a cell type fill and cover method of construction. In order to measure the rate of settlement at this landfill site a section of the fill was selected for which elevation readings had been obtained in 1957 and where no additional filling has been carried out since that time. Elevation readings were obtained at 12 surveying points for this section. Location of these surveying points is shown in Figure III-37. Cumulative settlements for the period 1957-1967 inclusive is presented in Table III-10. Surveying points 2, 8, 9, and 11 are located at the edge of the levee and exhibit less settlement than other points which are located on the landfill. Depth of the fill at these points averages between 25 and 30 feet.

TABLE III-10

SETTLEMENT RECORD AT SITE NO. 10

Surveying Point	1	2	3	4	5	6	7	8	9	10	11	12
Settlement (ft)	5.4	0.8	5.7	3.9	1.8	3.6	3.9	2.8	0.6	2.8	1.0	5.3

Site No. 11

This site is also being constructed and operated by a public agency. This fill is being constructed in stages with some areas now completed. Two of these areas have been monumented by the operating agency and surveys are being incorporated in this project for settlement study only.

In one area a grid system of 14 monuments has been established. Each monument consists of a brass tag set in a six inch concrete cylinder; each tag is stamped with its number, the date it was set, and the depth of refuse fill at that location. The monuments are spaced 200 feet in one direction and 150 feet in the other direction. All were set in December of 1964 and have been periodically surveyed for elevation changes since that time. The cumulative settlement for each monument through April 1967 is presented in Table III-11 for 100 series monument numbers. The location of these monuments is shown in Figure III-38.

In a second area, a grid system was established with 200 feet spacing in each direction, 15 monuments of the type described for the first area were set. These monuments were set in July of 1965 and have been monitored periodically since that time. The cumulative settlement for each monument at this area (through April 1967) is presented in Table III-11 for 300 series monument numbers. The location of these monuments is shown in Figure III-39.

TABLE III-11

SETTLEMENT RECORD AT SITE NO. 11

Monument Number	Depth of Fill (ft)	Cumulative Settlement (ft)
101	25	0
102	60	0.46
103	55	0.51
104	75	0.65
105	60	0.40
106	125	0.89
107	25	0.01
108	65	0.89
109	95	1.99
110	115	2.26
111	150	1.82
112	175	3.13
113	100	4.70
114	100	5.42
301	140	2.30
302	155	3.30
303	90	2.06
304	70	0.70
305	55	1.50
306	160	2.84
307	100	2.16
308	40	0.52
309	30	0.43
310	135	2.69
311	50	1.10
312	25	0.15
313	105	2.68
314	70	1.35
315	40	0.82

CHAPTER IV

GAS MOVEMENT THROUGH POROUS MEDIA

Natural soils constitute an economical source of raw material for construction of gas barriers around sanitary landfills. In order to study the suitability of various soils for gas barrier membranes, a laboratory experiment was carried out for this project. The objective of this experiment was to determine the gas permeability characteristics of various natural soils under a range of moisture content and gas pressure conditions. A laboratory diffusion column was built for this experiment and a gas chromatograph (Varian Aerograph Model 90P) was used for performing the required gas analyses. In this chapter the problem of gas movement through porous media is discussed and theoretical solutions for this problem are presented. Details of the experimental procedure and analysis of the results of the laboratory experiment are also included in this chapter.

THEORETICAL CONSIDERATION

Flow of compressible fluids in porous media can be represented by the following general formula:

$$F_x = -D_x \frac{\partial c}{\partial x} - \frac{K}{\mu} \frac{\partial P}{\partial x} \qquad (1)$$

where F_x = flow through a unit effective area of the medium perpendicular to the direction of transport

D_x = a coefficient representing the effect of dispersion and/or diffusion

$\frac{\partial c}{\partial x}$ = concentration gradient of the gas normal to the plane of interest

K = coefficient of intrinsic permeability of the porous medium

μ = viscosity of the combined gases passing through the medium

$\frac{\partial P}{\partial x}$ = pressure gradient in the direction of flow

In the absence of pressure gradient, i.e., when $\frac{\partial P}{\partial x} = 0$, equation (1) is reduced to Fick's First Law which expresses the flow of gases through porous media by molecular diffusion.

Using equation (1) and applying the principle of conservation of mass to a rectangular volume element of the porous medium, one can develop the following mass transport equation for steady flow of gases through a porous medium:

$$\frac{\partial}{\partial t}\left[c+\left(\frac{1-\theta}{\theta}\right)\rho q\right] = \frac{\partial}{\partial x}\left(D_x\frac{\partial c}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y\frac{\partial c}{\partial y}\right)+\frac{\partial}{\partial z}\left(D_z\frac{\partial c}{\partial z}\right) - \frac{\partial}{\partial x}(\bar{v}_x c) - \frac{\partial}{\partial y}(\bar{v}_y c) - \frac{\partial}{\partial z}(\bar{v}_z c) \qquad (2)$$

where

c = fluid phase concentration

t = time

θ = porosity

ρ = mass density

q = solid phase concentration/unit weight solid

x,y,z = distance in rectangular coordinates

$D_{(x,y,z)}$ = diffusion-dispersion coefficient in x, y, or z direction

$\bar{v}_{(x,y,z)}$ = average interstitial velocity in x, y, or z direction

For steady flow in a nonabsorbent media, equation (2) is simplified to:

$$\frac{\partial c}{\partial t} = \nabla^2 (Dc) - \nabla \bar{v}c \qquad (3)$$

where ∇ is a differential operator.

For one dimensional flow, equation (3) is further simplified to:

$$\frac{\partial c}{\partial t} + \bar{v}\frac{\partial c}{\partial x} = D\frac{\partial^2 c}{\partial x^2} \qquad (4)$$

If the trace component is introduced as a step function, i.e., subject to the conditions:

$$c\,(x,o) = 0 \quad \text{and} \quad c\,(o,t) = c_o \qquad (5)$$

the solution of equation (4) can be represented by (Reference 2):

$$\frac{c}{c_o} = \frac{1}{2}\left[\operatorname{erfc}\left(\frac{x-\bar{v}t}{2\sqrt{Dt}}\right) + \left(\exp\frac{\bar{v}x}{D}\right)\operatorname{erfc}\left(\frac{x+\bar{v}t}{2\sqrt{Dt}}\right)\right] \qquad (6)$$

If the trace component is introduced as a finite pulse, i.e., subject to the conditions:

$$c\ (X,0) = 0$$

$$c\ (o,t) = \begin{cases} 0 & t = 0 \\ c_o & 0 < t < t \\ 0 & t = t_1 \end{cases} \tag{7}$$

The solution of equation (4) can be expressed by (Reference 3):

$$\frac{c}{c_o} = \frac{1}{2}\left[\operatorname{erfc}\left(\frac{x-\bar{v}t}{2\sqrt{Dt}}\right) - \operatorname{erfc}\left[\frac{x-\bar{v}\ (t-t_1)}{2\sqrt{Dt}}\right]\right] \tag{8}$$

Finally, for an instantaneous pulse or delta distribution of the trace component, Bennet and Kaufman (Reference 4) have shown that the solution of equation (4) will take the following form:

$$c = \frac{M}{2\theta A\sqrt{\pi Dt}} \exp\left[-\frac{(x-\bar{v}t)^2}{4Dt}\right] \tag{9}$$

where M is the total amount of trace component and is expressed by:

$$M = Q\int_0^{\infty} cdt \tag{10}$$

Q in equation (10) represents the steady rate of flow of a carrier gas through a column with cross-sectional area A and infinite length.

The diffusion-dispersion coefficient, D, can be obtained using a modified form of equation (9) for a column of length, L, (Reference 4) as follows:

$$c = \frac{\bar{v}\int_0^{\infty} cdt}{2\sqrt{\pi Dt}} \exp\left[-\frac{(L - \bar{v}t)^2}{4Dt}\right] \tag{11}$$

The term $\int_0^{\infty} cdt$ is obtained by integrating the concentration history curve. Any point on the concentration history curve can be used to calculate the diffusion-dispersion coefficient, D, from equation (11). For this purpose the point corresponding to mean residence time can be used in all tests. The mean residence time is determined from the carrier gas flow rate, Q, and the column retention volume, L θA, or from the centroid of the concentration history curve. Using the mean residence time as suggested by Bennet and Kaufman (Reference 4), then:

$$D = \left[\frac{L \int_{o}^{\infty} c\,dt}{2\sqrt{\pi}\, c_m t_m^{3/2}} \right]^2 \tag{12}$$

The subscript, m, indicates the values at the mean flow-through time. Another method for calculating D is by using the expression given by Littlewood (Reference 5):

$$D = \frac{J^2 \bar{v}^2}{32\ t_m} \tag{13}$$

where J is the width of the base line on the concentration history curve defined by tangents constructed through the straight line portions of the curve. The concentration history curve has a bell-shape form. Several correction factors should be introduced in the calculation of the coefficient, D, to take into account the effect of pressure changes, void volume in the column, column length, etc. Equation (12) was used for calculating the coefficients of diffusion-dispersion for this experiment.

EXPERIMENTAL METHOD

In order to determine the diffusion-dispersion coefficient of methane, the principal explosive gas generated in sanitary landfills, for a variety of porous media, a test unit was fabricated in the Oakland laboratory of Engineering-Science, Inc. This test unit consisted of a quarter-inch wall, plexiglass column with a 4 inch inside diameter and a three foot length. Provisions were made for the flow of carrier gas and the injection of a tracer at one end of the column as well as for manometer and gas chromatograph connections at the opposite end. Detailed drawings of the test column and other accessories are shown in Figures IV-1 through IV-3. A picture of the laboratory setup is presented as Figure IV-4.

Nitrogen was used as the carrier gas and methane was used as the tracer gas in this experiment. For each test the porous medium (tested soil) was compacted in the column according to standard methods for compaction tests (ASTM D698). Before the soil compaction was carried out, two 4-inch cylindrical sections were connected to both ends of the column which were removed after the completion of the compaction process. The use of additional column sections was to insure a higher degree of uniformity of compaction in the 36-inch long column as used for the gas flow test. Soil porosity, density, and degree of compaction were determined by testing the compacted soil in the removable bottom 4-inch section of the column. Although it is possible that the soil in the bottom 4-inch section was more densely compacted than other parts of the column, porosity and density parameters for this section were assumed to be representative of the medium in the test column. The column was filled by adding soil, one layer at a time, in lifts equivalent to the diameter of the column (4-inches). This layer was then compacted, using a 5-pound compaction hammer with a 12-inch drop. After the soil was compacted in the column, the column was installed on the test stand and was flushed with pure nitrogen until all of the air in the pore spaces of the medium and the empty space within the end connections of the column was replaced by nitrogen.

When the flushing operation was completed, nitrogen flow to the column was cut off and a known volume of methane (0.5 or 1 percent of the void space in the column) was injected in the column at the rate of one milliliter per minute. Void space in the column consisted of empty sections in the end connections and the pore space of the test medium. Soil porosity for each test condition was evaluated by ASTM standard methods. The volume of tracer gas was then determined on the basis of total void space in the column. A methane volume of 0.5 percent of the column void space was injected into the column for soils with high porosity such as clay and silty clay, and for other soils a volume of one percent of that void space was injected. These percentage values were chosen on the basis of the sensitivity of the gas chromatograph used in the experiment. The Varian aerograph gas chromatograph used was capable of detecting methane concentrations as low as 0.1 percent on a volume basis. Therefore, a tracer volume of 0.5 to one percent of the void volume in the column was injected to insure the construction of a satisfactory histogram of methane at the opposite end of the column. The volume of tracer can be reduced when more sensitive detection devices are used for diffusion experiments.

Immediately after methane injection, the flow of nitrogen was restored at a predetermined rate and was maintained at that rate during the remainder of the test period. This method of introducing the tracer gas does not provide an ideal simulation of a pulse input; however, it was selected to minimize technical problems associated with introducing from 10 to 100 ml of tracer gas as an instantaneous pulse without disturbing steady state flow through the column.

Immediately after introducing the tracer into the column, samples were obtained from the opposite end of the column and were analyzed to construct the concentration history curve which formed the basis for determining the diffusion-dispersion coefficient correlative to the medium.

Gas sampling from the test column was carried out by direct connection of the column to the gas chromatograph. At low flow velocities and for very tight soils, where the time base on the concentration history curve was in excess of 48 hours, the sampling interval was adjusted according to the minimum time required for the gas chromatograph to analyze each individual sample. For methane, this period was approximately 20 minutes. However, at higher flow velocities, when samples must be analzed more frequently, gas samples were stored in labeled gas burettes and were later processed through the chromatograph. The test plan for the laboratory experiment is shown in Table IV-1.

Optimum moisture for each soil was determined in accordance with standard methods as contained in ASTM-D698.

Soils classified as sandy silt and silty clay, as shown in Table IV-1, were obtained from Site No. 6, and curves showing their grain size distribution are shown in Figure III-5. In order to obtain control values for soils with greater and lesser gross porosity, artificial soils of sand and kaolin clay were subjected to the diffusivity experiment. Grain size distribution curves for control soils are shown in Figures IV-5 and IV-6.

Tests of sand at optimum moisture content were not considered because there is no such accepted optimization. Sand may contain moisture in all ranges from surface dry to complete saturation. Any appreciable degree of moisture within this range would create a condition where stable water would collect at the bottom of the medium and the interstitial volume above the surface of such surface water would be at 100 percent relative humidity. Gas flow tests made under these conditions could not be correlated with moisture content and would, therefore, be meaningless.

TABLE IV-1

TEST PLAN FOR GAS DIFFUSION EXPERIMENT

Porous Media	Moisture Content					
	Air Dry			Optimum		
	Inflow Gas Pressure					
	0.25 Inches Water	4.0 Inches Water	12.0 Inches Water	4.25 PSi	5 PSi	20 PSi
Nitrogen	x	x	x	-	-	-
Sand	x	x	x	-	-	-
Sandy Silt	x	x	x	x	x	-
Silty Clay	x	x	x	x	x	x
Kaolin Clay	x	x	x	x	x	x

PSi = 27.673 inches of water (4°C)

x = test applicable

The test using a nitrogen-filled column was used as an initial control to provide a basis for comparison for the entire experiment. It is further concluded that the diffusion-dispersion coefficient obtained from runs using nitrogen would be equivalent to those coefficients which would be attained if gravel, or any other porous material having a large effective size and a high uniformity coefficient, were tested.

Tests performed at landfill sites which were subjects of this study, as well as tests made at other sites (Reference 6), failed to detect gas pressures within the fill in excess of a few inches of water; test results showed a range of from zero inches (undetectable) to slightly less than four inches of water. The upper limit test pressure of 12 inches of water was established to provide upper-range data for pocket pressures which might exist in unusual cases.

RESULTS OF EXPERIMENTS

Concentration history curves were prepared for each experimental test run as indicated by the test plan. These history curves present the methane concentration at the low pressure end of the porous media as a function of time elapsed following release of the pulse discharge. History curves for all test runs with the exception of sandy silt, silty clay, and kaolin clay at optimum moisture and 20 PSi pressure are included as Figures IV-7 through IV-21. Quantities of gas moving through clays at optimum moisture content, even at 20 PSi (553.5 inches water) were so low as to be virtually unreadable and the diffusion-dispersion coefficient for these tests was assumed to be smaller than the smallest of values obtained for these coefficients under the air dry condition.

Values of t_m and c_m were calculated from the position of the centroid of concentration history curves (or the mass numerical centroid). The substitution of these constants in equation (12) yielded the value of the diffusion-dispersion coefficient for the case under consideration. These coefficients are presented in Table IV-2; the dimension is in cm^2 per second. The term "No Flow" in the same table indicates that for the specific porous medium under test, no appreciable flow of the carrier gas could be detected for the given inflow conditions. Basic data on porosity, density, and moisture content of the media, inflow gas pressure, and rate of flow of nitrogen through the column are also presented in Figures IV-7 through IV-21. Relative compaction of the soil material for each test condition are presented in Table IV-2. These compaction values were determined by comparing the density of the test medium with the maximum density of the same soil at optimum moisture in accordance with ASTM Standard Method (ASTM-D698).

ANALYSIS OF RESULTS

These results clearly indicate that the rate of movement of methane by diffusion-dispersion is considerably slower through soils with fine particles than through those with coarser particles. This conclusion appears to hold for both air dry and optimum moisture condition and under all conditions of inflow gas pressure. Air dry kaolin clay forms almost a total barrier to gas movement under a pressure of 4 inches of water. The

TABLE IV-2

DIFFUSION-DISPERSION COEFFICIENTS FOR METHANE IN VARIOUS POROUS MEDIA

D (cm^2 Per Second)

Porous Media	Moisture Content							
	Air Dry				Optimum			
	Inflow Gas Pressure							
	0.25 Inches Water	4.0 Inches Water	12.0 Inches Water	Compaction Percent	4.25 PSi	5 PSi	20 PSi	Compaction Percent
Nitrogen	1.34	37.6	58.4	-	--	--	--	-
Sand	0.0575	0.578	4.85	72	--	--	--	-
Sandy Silt	0.0317	0.152	0.239	62	0.033	0.035	--	84
Silty Clay	0.026	0.088	0.093	67	N.F.	N.F.	<0.026	90
Kaolin Clay	N.F.	N.F.	0.012×10^{-3}	41	N.F.	N.F.	$<0.012 \times 10^{-3}$	90

PSi = 27.673 inches of water (4°C)

N.F. = no detectable flow

possibility of molecular diffusion through kaolin clay and other soils can not be overlooked, but the general consensus is that flow by molecular diffusion can not exceed the flow under combined action of diffusion and dispersion. The latter flow is very small for clay, even when the inflow pressure is as high as 12 inches of water. Due to the limitation on instrumentation it was not possible to conduct static molecular diffusion tests in this experiment. However, it is generally stated that molecular diffusion increases in direct relation with porosity of the medium in which diffusion takes place (Reference 6). Therefore, for fine soils such as clay or silt, methane may have a higher molecular diffusion coefficient than for coarser soils. Because of the lack of data on static diffusion of methane in the soils tested in this experiment it is not possible to distinguish between the molecular and dispersive components of the coefficients presented in Table IV-2. However, the high convective movement of gases in coarse soils is responsible for the high diffusion-dispersion coefficients of methane in these soils.

In addition to the flow occurring by diffusion-dispersion, a considerable volume of gas also passes through the medium by convective movement when a pressure gradient exists along the column.

This experiment was carried out with nitrogen and methane as carrier and tracer gases respectively. Large volumes of CO_2 are also generated in sanitary landfills which diffuse and flow out of the fill in various directions. No general correlation can be developed to arrive at diffusion-dispersion coefficients of CO_2 by using the measured values of these coefficients for methane under different experimental conditions. However, it can be stated that, because of the higher molecular weight of CO_2 (44 compared to 16 for CH_4), corresponding coefficients for this gas will have a smaller numerical value than those presented for methane in Table IV-2.

Example

In order to demonstrate the practical results obtainable from this experiment, a sample calculation for gas flow through porous membranes is presented in this section. It is assumed that a landfill has a sidewall gravel membrane with an area exposed to gas of 100,000 square feet and that the following conditions exist:

Thickness of the gravel membrane:	5 feet
Methane concentration inside the fill:	50 percent
Methane concentration outside the fill adjacent to the membrane:	5 percent

The rate of flow of methane, caused by diffusion-dispersion, through the sidewall membrane is calculated by applying Fick's formula:

$$F = -D\,A\,\frac{\partial c}{\partial x} \qquad (14)$$

If it is assumed that the nitrogen-filled column simulates conditions applicable to gravel as previously discussed, the flow of methane by diffusion-dispersion under a positive differential pressure of 0.25 inches of water can be calculated as follows:

$$D = \frac{1.34}{929} = 0.00144 \text{ ft}^2/\text{sec}$$

where

1.34 = diffusivity-dispersion coefficient for gravel (nitrogen) in cm^2/sec

929 = cm^2/ft^2

Also $A = 100{,}000\ ft^2$

and $-\frac{\partial c}{\partial x} = -\frac{0.05 - 0.5}{5} = 0.09$ percent/ft

then $F = 0.00144\ (100{,}000)\ (0.09) = 12.96\ ft^3/sec$

Calculated values of flow rates, by diffusion-dispersion, through other soil membranes with dimensions and concentrations as per the example are presented in Table IV-3. The degree of compaction of these soil membranes is assumed to be the same as those presented in Table IV-2.

TABLE IV-3

CALCULATED FLOW OF METHANE BY DIFFUSION-DISPERSION THROUGH SOIL MEMBRANES

(Ft^3 Per Second)

Porous Media	Moisture Content					
	Air Dry			Optimum		
	Differential Gas Pressure					
	0.25 Inches Water	4.0 Inches Water	12.0 Inches Water	4.25 PSi	5 PSi	20 PSi
Nitrogen	12.96	364.40	566.00	--	--	--
Sand	0.57	5.60	47.00	--	--	--
Sandy Silt	0.31	1.47	2.32	0.32	0.34	--
Silty Clay	0.25	0.85	0.90	--	--	0.25
Kaolin Clay	--	--	0.12×10^{-3}	--	--	0.12×10^{-3}

Area: $100{,}000\ ft^2$

Thickness: 5 ft.

In addition to the flow component occurring under diffusion-dispersion phenomenon, an additional flow of methane also passes through the membrane due to the pressure gradient (convective flow). This component can be represented by

$$Q = -\frac{KC}{\mu}\frac{\partial P}{\partial x} \qquad (15)$$

Where Q = flow in cubic feet per second

K = intrinsic permeability of the porous medium in ft^2

μ = viscosity of the combined gases passing through the membrane in $lb\text{-}sec/ft^2$

$\frac{\partial P}{\partial x}$ = pressure gradient in lb per ft^2/ft

C = average methane concentration in the total volume of the gas passing through the membrane

This flow component may be quite appreciable for the case of highly permeable media such as sand and gravel whereas it will be rather insignificant for fine soils and when subject to small pressure gradients. However, when a fine soil such as silty clay or clay is compacted under optimum moisture conditions to 90 percent or better of the maximum density, the gas permeability of the medium will be so small that flow by pressure gradient will be reduced to inappreciable quantities. During the course of this experiment no attempt was made to measure the gas permeability of various media used in the laboratory. However, flow rates for nitrogen were measured for each test condition. These flow rates are recorded in Figures IV-7 through IV-21. In order to obtain an estimate of flow of methane caused by pressure gradient across the hypothetical membranes used in the above example, it is assumed that under the corresponding pressure gradients the total flow rate across the membrane can be calculated by multiplying the flow rates for nitrogen through the column by a factor corresponding to the ratio of the area of the membrane to the cross sectional area of the column. Because of the assumption that methane concentration in the landfill is 50 percent, the component of flow of methane occurring under pressure gradient can be calculated as follows:

For the case of an empty column from Figure IV-7,

Q = inflow gas rate = 170 cc/min for a pressure drop of 0.25 inches of water along the test column (based on atmospheric pressure at end of test column)

or

$$Q = \frac{170 \times 3.531 \times 10^{-5}}{60} = 0.0001 \text{ ft}^3/\text{sec}$$

On the other hand, the cross sectional area of the four inch I.D. column is:

$$A = 0.0872 \text{ ft}^2$$

Therefore, flow of methane due to a pressure drop of 0.25 inches of water for a gravel membrane five feet thick and 100,000 ft^2, when methane concentration in the gas is 50 percent, can be obtained from

$$Q_m = \frac{100{,}000}{0.0872} \times 0.5 \times 0.0001 = 57 \text{ ft}^3/\text{sec}$$

where

Q_m = convective flow through the membrane

In the same manner flow of methane due to pressure gradient for all other test conditions was calculated. The results of these calculations are presented in Table IV-4.

Total combined flow of methane, due to dispersion-diffusion and pressure gradient across the hypothetical membranes considered in this chapter, is presented in Table IV-5.

Calculated flow rates shown in Table IV-5 substantiate the presumption that fine textured soils such as sandy clay, silty clay, or clay form an effective barrier to gas movement even at low moisture content. These soils, when compacted at optimum moisture content to 90 percent (or better) of the maximum density, prevent any appreciable flow of methane or other gases under differential pressures of one or more atmospheres. A discussion on the feasibility of constructing soil membranes in sanitary landfills is presented at the end of this chapter.

TABLE IV-4

CALCULATED RATES OF FLOW OF METHANE DUE TO PRESSURE GRADIENT THROUGH SOIL MEMBRANE

(Ft^3/Second)

Porous Media	Moisture Content					
	Air Dry			Optimum		
	Inflow Gas Pressure					
	0.25 Inches Water	4.0 Inches Water	12.0 Inches Water	4.25 PSi	5 PSi	20 PSi
Nitrogen	57.0	2515.0	4760.0	--	--	--
Sand	1.0	335.0	1106.0	--	--	--
Sandy Clay	0.67	27.65	96.5	0.59	1.20	--
Silty Clay	1.0	5.70	22.4	--	--	<1.01
Kaolin Clay	--	--	1.34	--	--	<1.34

Area: 100,000 ft^2

Thickness: 5 ft

TABLE IV-5

TOTAL FLOW OF METHANE THROUGH SOIL MEMBRANES

(Ft^3/Second)

Porous Media	Moisture Content					
	Air Dry			Optimum		
	Inflow Gas Pressure					
	0.25 Inches Water	4.0 Inches Water	12.0 Inches Water	4.25 PSi	5 PSi	20 PSi
Nitrogen	70.0	2879.0	5326.0	--	--	--
Sand	1.6	340.6	1153.0	--	--	--
Sandy Clay	1.0	29.1	98.8	0.9	1.5	--
Silty Clay	1.3	6.5	23.3	--	--	<1.3
Kaolin Clay	--	--	1.3	--	--	<1.3

Area: 100,000 ft^2

Thickness: 5 ft.

DISCUSSION OF EXPERIMENT

Numerical values for diffusion-dispersion coefficients of methane in various porous media given in Table IV-2 establish the trend of gas diffusion characteristics for these media under various conditions of moisture content and gas pressure. However, the experiment is subject to several errors resulting from instrumentation error or the effect of variations of other parameters such as tortuosity and absorbtion characteristics of the porous media. Following is a list of the main parameters which may have affected the calculated values of diffusion-dispersion coefficients:

Temperature Variation

It is the usual practice to conduct gas flow experiments under controlled temperature conditions. However, for this experiment, it was not considered feasible to construct a special constant-temperature room. The tests were conducted at room temperature which was subject to variation from 18 to 24°C. The discrepancy due to temperature variation is more pronounced for tests of long duration and is practically negligible for tests of short duration.

Absorbtion

The assumption of non-absorbing media, which was made in developing the basic differential equation of flow, is questionable because methane molecules may be absorbed on soil particles and water films around these particles. This phenomenon may be responsible for the non-symmetrical shape of the concentration history curves for tests of long duration (Figures IV-7 through IV-21). This factor could not be determined without independent research into the nature of absorbtion phenomenon for the gas and medium used in this experiment.

Tortuosity

Tortuosity of the porous medium affects the pattern of gas dispersion and causes a deviation from the assumed one-dimensional flow condition. Determination of the effect of this parameter for natural soils is in itself a broad subject for research and was not included in this program.

Effect of Fluid Compressibility

Reduction of pressure along the length of the column causes an increase in the volume of the gas which affects the dispersion characteristics of the tracer. The effect of the pressure variation in the column can be calculated from the following formula (Reference 4):

$$\frac{D'}{D} = \frac{9\left[\left\{\left(\frac{Pin}{Po}\right)^4 - 1\right\}\left\{\left(\frac{Pin}{Po}\right)^2 - 1\right\}\right]}{8\left\{\left(\frac{Pin}{Po}\right)^3 - 1\right\}^2} \qquad (16)$$

where

D' = corrected diffusion-dispersion coefficient
D = calculated diffusion-dispersion coefficient
Pin = inflow pressure
Po = outflow pressure

For the maximum inlet pressure in the laboratory experiment where, Pin = 34.7 PSi and Po = 14.7 PSi, then D' = 1.04 D; the correction due to the pressure variation does not exceed four percent. Therefore, it can be concluded that the effect of fluid compressibility is not significant for the range of pressure variations encountered in this experiment and can be neglected without introducing serious errors in the final results.

Method of Injection of the Tracer

Due to the low sensitivity of the gas chromatograph and large volume of the test column, it was necessary to inject from 50 to 100 ml of methane into the column for satisfactory detection at the far end. This large volume of tracer gas, however, made the introduction of gas as an instantaneous pulse very difficult. For this reason the tracer was injected into the column at a rate of 1 ml per minute. However, this method of injection generated a finite pulse of duration t_1, in which t_1 is a function of the volume and rate of injection of methane into the column. Under these conditions, equation (8) is a more representative solution for the problem than equation (9). However, determination of C_o, or input concentration was impractical. Moreover, equation (8) is not amenable to graphical or mathematical solution.

Gas Chromatograph

The sensitivity and accuracy of the chromatograph is also a major factor affecting the accuracy of the concentration history curve for methane. The chromatograph used in this experiment (Varian Aerograph Model 90 P) theoretically can detect methane concentrations as low as 0.05 percent. However, in practice and with the use of a recorder, the minimum detectable limit is approximately 0.1 percent. The limit of accuracy of the above chromatograph was, however, satisfactory for the purposes of this experiment.

Because the above factors affected all of the tests rather uniformly, it can be concluded that the general results of this experiment are valid even though the numerical values of the diffusion-dispersion coefficients may be at slight disparity with the exact value of these coefficients. More accurate values for these coefficients could be developed by conducting experiments under highly controlled conditions and by the use of more sophisticated instrumentation than that considered feasible for this experiment. Considering that the objective of these tests was to determine the suitability of various natural soils for gas barriers, it is concluded that this goal has been well achieved and that more refined testing would be required to expand the scope of this experiment and to develop diffusion-dispersion and gas permeability coefficients for a wider range of porous media.

CHAPTER V

DESIGN AND IMPLEMENTATION OF FIELD GAS BARRIERS AND CONTROL DEVICES

Biological decomposition of refuse in a sanitary landfill produces gases of which the three major components are carbon dioxide, methane, and nitrogen. Of the combustible gases, methane is the major constituent and hydrogen, when present, is minor in quantity. Whereas gas emission from cracks in the surfaces of sanitary landfills is not uncommon and this phenomenon is well known, travel of gases, particularly combustible gases, from landfills into the adjacent ground is of newer concern and has rarely been reported in the literature.

Results of this study, as well as other studies, have shown that these gases, under certain conditions and in particular soil types, can move laterally significant distances from landfills into adjacent soils. High methane concentrations have been measured for the soil atmosphere at great distances from landfills at a depth of two feet from the ground surface. Experience has shown that methane concentrations will decrease toward the ground surface, reaching practically zero value at the surface if the gas is allowed to diffuse freely into an open space where it is readily diluted by air. However, if methane gas is trapped in a confined air space, it is possible that the concentration will build up to an inflammable level.

It is the objective of this chapter to discuss and evaluate installations, devices, and other controls which can effectively lower lateral, subsurface movement of gas.

SHALLOW CONTROL DEVICES

The simplest and probably the least expensive, but not always the most effective, method of surface gas control in a sanitary landfill is through the use of "tiki" burners. These burners consist of pipes installed near the periphery of and into the landfill so that the pipe penetrates vertically through the cover of the landfill, and so that the surface around the pipe is sealed to prevent leakage. Gas, generated in the immediate vicinity of the pipe, is collected through the pipe and is burned at the top. A special hood is utilized to prevent wind from extinguishing the flame. Some burners are equipped with automatic reignition devices. The height of burners varies in existing installations but, for safety, it should be no less than 10 feet above grade. Two representative "tiki" burners are shown in Figure V-1. This method of control is practiced at Sites No. 4 and No. 8.

A more sophisticated method of gas burning is the installation of a network of perforated pipes, buried in a shallow gravel-filled trench, on or around the landfill. The gas collected in these pipes is conducted to a central station where it is burned at the head of one or more standpipes. This method is practiced to a limited extent at Site No. 4.

Both of these control methods are effective to a limited extent in reducing problems associated with gas movement. The main usefulness of these methods lies in reducing the danger of gas explosion or of fire in the immediate vicinity of the landfill. They do not significantly inhibit the flow of gas through soil into surrounding areas.

DEEP CONTROL INSTALLATIONS

A highly effective method for the control of gas movement in areas characterized by heavy soil materials consists of the excavation of a deep cut-off trench around the fill, and the backfilling of this trench with gravel. This method has been successfully applied at Site No. 5. The explanation for this success is that the gravel-filled trench has produced a vent for the major fraction of the gas which is flowing under pressure and has thereby substantially reduced the flow of gases beyond the trench. This control system was implemented by a public agency to eliminate problems resulting from gas moving underground from the landfill and surfacing in the yard of a house located at a distance of 115 feet from the edge of the fill. Analysis of gas samples taken from shallow probes in the above mentioned yard prior to installation of the control system showed the following composition:

> CH_4, 42 percent; CO_2, 33 percent; O_2, 0.8 percent; and sulfur products, a trace.

In order to reduce these excessive methane and CO_2 concentrations, a trench 20-feet deep, 30-inches wide, and about 1,050-feet long was excavated near the fill. This trench was backfilled with No. 2 gravel. Most of the soil at this site is composed of silty clay with varying contents of diatomite, Mechanical analyses of a soil sample from this site indicates that 70 percent of the soil particles have a diameter of less than 0.02 millimeter (Figure III-4). These conditions are very conducive to formation of a gas barrier around the fill which may result in pressure buildup in the landfill.

If a horizontal layer of coarser soil exists around the landfill, it tends to act as a "chimney" for transferring the generated gases laterally from the fill. In such a case, a gravel-filled trench which intercepts this conducting stratum will act as a vent and will significantly reduce the transfer of gases beyond the trench.

The effectiveness of the control installation at Site No. 5 is verified by analyses of gas samples taken in the same yard more than one year after the installation of the control system which showed the following gas compositions:

CH_4, 0 percent; CO_2, 2.2 percent; O_2, 17.7 percent.

Test probes on the fill side of the trench showed that no change in the composition of gases had taken place after implementation of the trench system.

The marked reduction in CH_4 and CO_2 concentrations indicate that the problem of gas movement was virtually eliminated in the area under consideration.

BARRIER (MEMBRANE) CONSTRUCTION

Newly developed landfill areas at sites where the surrounding soil is porous may require the initial construction of positive barriers to inhibit diffusion and effectively bar convection.

Compacted Soil Barriers

Laboratory experiments (Chapter IV) have shown that certain compacted soils can be used as satisfactory gas barriers. Soil which possesses a wide range of grain size distribution with an appreciable fraction smaller than 5 microns and which are capable of being compacted in the field to better than 95 percent of maximum density at optimum moisture may be placed, using standard construction techniques, to create an effective gas barrier, (the greater the percent of compaction, the better the barrier).

Transporting and compacting equipment, presently used for earth work involving quantities of earth contemplated for a project of this magnitude, require a minimum of 10 feet of compacted width at their narrowest section for economical operation.

Saturated Soil Barriers

Soil which is maintained in a completely saturated condition provides for nearly 100 percent efficiency in stopping both the diffusive and convective flow of gas.

The effectiveness of these barriers to maintain such saturated conditions depends on the following conditions:

(1) The use of a core soil with a narrow grain size distribution, such as clay.

(2) The use of a core width such that drying at the center of the core will not occur for a relatively long period of time (in excess of one month). Core drying will occur when moisture moves by capillary action laterally into the surrounding soil matrix.

(3) The placement or use of a surrounding soil matrix with a narrow grain size distribution in the range of 2 mm or larger. The matrix should be compacted only to the point that it will maintain stability. The large porosity (approximately 40%) thusly produced will effectively break capillary action at the core interface.

The use of a highly hygroscopic chemical such as calcium chloride as an admixture to the core soil will materially aid in retention of soil moisture.

The construction of saturated soil barriers is presently beyond the existing state-of-the-art, and much field testing of methods and techniques will be required before such construction can be directly specified as a "standard method."

Other Gas Barriers

Although not tested in this study, other materials may be used to form a barrier. Such a material must comply with the following requirements:

(1) It must be relatively impervious to moisture and to gas.

(2) It must retain its imperviousness over a long period of time (50 years) while being subject to alternate wetting and drying and to any corrosive conditions inherent in its soil-refuse surroundings.

(3) It must be capable of being placed into the bottom of the dump site deep enough to provide an effective cut-off.

(4) Under certain conditions it must be capable of retaining natural soil outside of the dump area.

Steel Sheet Piling: The use of properly designed steel sheet piling could satisfy the above requirements. Although gas may penetrate surrounding soil through the piling interlocking joints, the quantity of such gas will be minor. Steel sheet piling may be installed to provide a barrier for the full height of the refuse fill or may be used as a sub-surface cut-off in conjunction with a gunited face.

Sheet piling should be designed to resist loads applied by fill and backfill and must be capable of being driven under prevailing site conditions without splitting or rupturing. Piling sections should be chosen from those commercially available.

Prior to the specification of steel sheet piling a soil investigation should be made to:

(1) Verify feasibility of sub-surface driving.

(2) Determine corrosive potential of soil and resulting requirement for cathodic protection.

Pneumatically Applied Mortar (Gunite): Natural soil banks which have been stripped of vegetation and loose overburden and which will stand permanently at some specified slope could effectively be sealed against gas penetration by guniting the exposed surface. The application of a minimum of 2 inches of gunite to structurally stable slopes is currently recognized as an effective method of the controlling surface erosion of exposed banks and may also reduce gas movement, however, shrinkage cracks and cracks due to thermal action will allow gas to leak through the barrier. This leakage may be reduced through the application of a bituminous crack sealant or the use of flexible joint fillers during construction.

A soil test should be made of the natural bank material to verify that no constituents are present which would react detrimentally with cement.

Other Materials: Certain other materials and processes may prove to have merit under certain site conditions. The use of a bitumastic material may prove feasible for sealing porous rock faces and certain newly developed plastic materials may be used to replace or augment other barriers. These materials are soft and great care must be exercised in landfill operations to avoid their penetration. Further, their durability under conditions prevailing in sanitary landfills has not been determined.

DESIGN OF FIELD GAS CONTROL SYSTEMS

Three gas control systems were developed and designed during this study. One of these systems is to be installed at Site No. 1, the second system was installed at Site No. 5, and the third is planned for installation at Site No. 8. All of these sites are completed sanitary landfills. Following is a detailed description of the control system design at each of these sites:

Control System at Site No. 1

Site No. 1 is a completed sanitary landfill which was constructed in a depression created by gravel mining operations. A general description of this site and the history of filling operations is presented in Appendix B. Pertinent information on the nature of the soils around this landfill is presented in Chapter III and Table III-2. The natural soil at this site consists predominantly of sand and gravel, which allows easy passage of gases through the soil. The results of gas sampling and analyses given in Chapter III indicate that methane and carbon dioxide from this landfill move a considerable distance through the soil into the surrounding areas. Methane concentrations as high as 10 percent, by volume, were detected at a distance of from 600 to 700 feet from the fill limit.

Due to the non-cohesive nature of soil at this site, excavation of a deep trench for construction of a gas barrier would be difficult and expensive. An alternative method of control was developed which could be installed at a fraction of the cost of a gas barrier membrane. The design of this alternative system consists of five wells, 30-inches in diameter and 60 feet deep, spaced at 40-foot intervals, at a minimum distance of 150 feet from the fill limit. The layout plan for this system is shown in Figure V-2. Because this landfill has an irregular boundary, the line along which the control wells are located was chosen so as not to intercept the fill. The selected position of the wells will help to control a wider section of the fill with the limited number of wells available for this system. Possible protection of a building located directly across the street from Site No. 1 from gas movement was another factor in determination of the location of the wells.

Each well is divided into three sections, respectively 33, 18, and 9 feet deep. Each section is filled with No. 2 gravel and is topped with a one-foot layer of concrete. Three, 6-inch pipes, 33, 51, and 60 feet in length, are installed in each well. The bottom section of each pipe is perforated along its appropriate length for collecting the gases from the first, second, and third sections of the well. The purpose of dividing each well into three independent sections was to prevent short circuiting at the surface and to insure that gas would be pumped from the entire cross section of the well. It is anticipated that the greatest benefit derived from the control system will occur in the upper strata of the soil where the surface is exposed to the atmosphere. In order to receive the greatest benefit possible and to reduce as much as possible the effect of soil energy loss, the upper section of each well, where such energy loss will be the smallest, is being made the deepest section. The depth of this upper section is predicated on trying to achieve, as near as possible, a true cubical zone of influence for this upper section at each well. The depths of the remaining sections have arbitrarily been made to be nearly one-half of the section directly above.

These pipes are connected to a 12-inch head pipe which is in turn connected to the suction side of a blower type air pump. Isometric drawings for this system are shown in Figure V-3.

The objective of this control system is to reduce the flow of methane beyond a plane passing through the axis of the wells by pumping a sufficient quantity of gas from a cubical volume of the soil centered around the same plane. In order to achieve this objective it is necessary to calculate the minimum rate of pumping of gases through the soil and, based on this rate, to choose a pump of proper size for the control system.

The rate of flow of methane through the soil can be determined through the application of Fick's equation:

$$F = -DA \frac{\partial C}{\partial X} . \tag{1}$$

The component parts of this equation were defined in Chapter IV. From the measured concentrations of methane it was found that an approximate concentration difference of 10 percent exists for a lineal distance of 25 feet (Figures III-12 and III-13) in a direction perpendicular to the fill limit. It is necessary to introduce the following assumptions for completion of the solution:

(1) Due to the gravelly nature of the soil around this site the pressure buildup in the fill does not exceed atmospheric pressure and no flow occurs due to pressure gradient across the plane of the wells.

(2) The coefficient of diffusion-dispersion for methane in the soil at this site is approximated by the experimental value of this coefficient for air dry sand in the laboratory experiment under 0.25 inches of water of inflow gas pressure (Chapter IV). This coefficient (Table IV-2) is equal to 0.0575 cm^2 per second (6.19×10^{-5} ft^2 per second).

(3) Gas flow takes place uniformly across the plane of the well axis under a uniform concentration gradient.

(4) The wells are effective at a 60 foot depth.

The rate of flow of methane across the plane of the wells can then be calculated as follows:

$$D = 6.19 \times 10^{-5} \text{ ft}^2 \text{ per second}$$

$$A = 60 \times 200 = 12{,}000 \text{ ft}^2$$

and $$-\frac{\partial c}{\partial x} = -\frac{0-0.1}{25} = 0.004$$

then $$F = .003 \text{ cfs} = 0.18 \text{ ft}^3 \text{ per minute (cfm)}$$

Therefore, if 0.18 cfm of methane is removed uniformly from the plane passing through the axis of these wells, the flow of gases beyond the line of wells will be effectively checked. Because methane concentration at the location of the wells is approximately 50 percent, a total volume of gas equal to twice the volume (0.36 cfm) of methane must be displaced.

The evacuation of gas from a soil prism surrounding the wells obviously requires the replacement of an equal volume from some source. In order to minimize replacement from the landfill gas atmosphere, it was concluded that the most efficient methane removal would be realized by pumping from the two outside and the center wells while atmospheric air diffused into the soil through the two remaining wells, thus creating a flushing action. In order to provide for the greatest positive removal of methane possible, the peak pumping rate was arbitrarily increased from the theoretical 0.36 cfm to 90 cfm.

To properly size the air pump for this experiment it is necessary to further determine the headloss through the soil and pipe system for the maximum pumping rate of 90 cfm.

The rate of energy loss through the porous medium and the pipelines may be calculated by using the following formula (Reference 7):

$$P_1^2 - P_2^2 = \frac{G^2 RT}{g\, A^2} \left(f \frac{L}{d}\right) \qquad (2)$$

where P_1 = Pressure at point 1 (lbs per ft^2)

P_2 = Pressure at point 2 (lbs per ft^2)

G = Mass flow rate of gas (lbs per sec.)

R = Gas constant

T = Absolute temperature (°F)

A = Area (ft^2)

f = Friction factor

L = Length of pipe (ft)

d = Diameter of pipe (ft)

g = Acceleration of gravity (ft per sec^2)

In order to further calculate the friction factor for the pipes, it is necessary to determine Reynold's number, expressed as:

$$N_R = \frac{Gd}{\mu g A} \qquad (3)$$

where μ = dynamic viscosity of gas (lbs-sec per ft^2)

and other terms are as defined above. For a given flow rate, Reynold's number can be calculated and use of the Moody diagram (Reference 7) will determine the friction factor, f, for a particular pipe used.

Head loss in 6" riser pipes (3 each in 3 wells: a total length of 450 ft at F = 10 cfm) is only 2.6 inches of water when calculated at sea-level pressure and 70°F. Pressure drop in the soil prism is incapable of exact determination, but application of approximations indicates an energy gradient equivalent to 60 inches of water with a deviation of ± 50 percent. The air moving equipment must, therefore, be capable of exhausting in excess of 90 cfm at a differential pressure varying from 1.5 to 3.3 psi. One piece of commercial equipment available to meet these requirements will deliver 110 cfm at 4 psi differential pressure, running at 2400 RPM and requiring 2.93 HP.

In order to establish the effectiveness of this control system, the following program of testing should be carried forward:

(1) Drill two lines of 9 probe holes each, spaced 10 feet on each side of the well line and centered thereon. Install 3 probes at depths of 5, 10, and 20 feet in each hole.

(2) Sample probes and analyze gas for methane twice, at a two week interval, prior to commencement of control system operation.

(3) Operate control system at varying rates of gas evacuation and at varying intervals of time. Sample probes and blower exhaust and analyze gas following each change in operating procedure.

Quantitative results of this operation and testing program cannot be predicted; therefore, a detailed program of operation and testing must be written to represent an ever-changing endeavor.

The public agency operating this sanitary landfill is currently planning to install the control system and testing equipment similar to this design. Results of tests on control system operation will be presented in the report on second year activities.

Control System at Site No. 5

Site No. 5 is a completed landfill of varying depth which was constructed in a large depression created by diatomite mining operations. A general description of this site and the history of filling operations is presented in Appendix B. Information on the nature of the soils around this landfill is presented in Chapter III and Table III-2. A description of an existing, deep control installation was given earlier in this chapter.

Presently, a botanic garden is being developed at this site by a public agency and several structures are constructed on the landfill at this site. Due to the upward movement of gases through the fill cover, considerable odor had been noticed adjacent to these buildings. Gas analyses indicated the existence of methane in the atmosphere in a greenhouse with a gravel floor. The concentration of methane was below the explosive limit.

Plans were under way at this site for the construction of another greenhouse. In order to prevent gases, generated within the landfill, from moving through the fill cover into the confines of this greenhouse it was decided to install a gas barrier beneath this structure. The foundation for this structure had already been constructed prior to the decision to install a barrier. Therefore, an asphalt type membrane was chosen as being the most positive, as well as the most economical, method of control. This membrane was extended to cover the top of the foundation, in order to prevent gas leakage from the area outside of the walls into the building. Previous research by Engineering-Science, Inc. (Reference 6) has indicated that an undamaged asphalt liner forms an effective barrier against gas movement. The liner used for this experiment is commercially available "Weathergard Fiberseal Liner" as manufactured by the MacMillan Ring Free Oil Company. The membrane consists of a multiple layer, fiber reinforced, asphalt laminate fabricated in place and is designed to be impervious to moisture. It is used for the containment of water in reservoirs, canals, etc., and erosion control. A detailed description of the liner is included as Appendix D. Following is a detailed account of the test site and installation procedure for this control system:

The greenhouse is approximately 12 feet wide and 25 feet long. It consists of a light weight aluminum and glass structure resting on a single course of concrete block set in a concrete footing. In order to install the gas control device under this greenhouse, the area within the foundation of the structure was excavated to a depth of 13 inches. A four-inch layer of No. 2 gravel was first placed at the bottom of this excavated area and probes were installed within the gravel. Two, three-inch perforated pipes were placed in the gravel at each end of this area, across the width of the structure (Figure V-4). Two risers were connected to the perforated pipes and were brought to the surface above ground to provide venting of the gravel base and to prevent excessive buildup of gas concentration under the asphalt membrane. A three-inch layer of sand was placed on top of the gravel and was compacted to form a smooth surface for placement of the liner. The liner was placed over the sand and was extended over the structure footing to provide positive sealing along the periphery of the structure (Figure V-5). After a curing period of five days and an application of a final asphalt seal coat to the liner a six-inch layer of pea gravel was placed over the asphalt membrane. This gravel layer forms the floor for the greenhouse and probes were also installed in this gravel (Figure V-6). The asphalt liner was given proper slope to allow adequate drainage for the greenhouse floor through one side of the foundation (Figure V-7). Probe plan location is shown in Figure V-8. Probe locations were as follows:

(1) Three probes were placed at a depth of 3.5 feet under the floor of the greenhouse.

(2) Five probes were placed on top of the 6-inch gravel layer beneath the liner. These probes were located at the center of the area and mid point between the center and corners of the foundation.

(3) Five probes were placed on top of the asphalt liner in the pea gravel layer directly above the previously located probes.

(4) Four probes were installed at various depths outside the foundation area and around the perimeter of the greenhouse structure.

In order to monitor the effectiveness of this control system, methane concentrations will be determined in gas samples collected from the probes installed over and under the asphalt membrane and also at other points under the greenhouse and in the vicinity of this structure. Comparison of these concentrations will provide a basis for determining the effectiveness of this control system. If the asphalt membrane is effective in preventing the upward movement of gases then methane concentration in gas samples obtained from the probes installed over the membrane will be much lower than that for probes which are installed under and around the greenhouse. Also, if the venting system is effective in carrying away the gases flowing into the gravel layer under the membrane, the efficiency would be manifested in low methane concentration in gas samples obtained from the probes installed in this gravel layer as compared to methane concentration at deeper points under and around the greenhouse.

The program of monitoring will, therefore, consist of sampling installed probes at frequent intervals and comparing the result of the analyses of these samples according to the location and depth of the probes. Detailed results of this sampling program will be presented in the final report on second year activities.

Control System at Site No. 8

This site is a completed landfill of varying depth which was constructed in a depression resulting from gravel mining operations. Extensive gas movement occurs from this landfill into the surrounding areas. Methane concentrations as high as 10 percent have been detected at a distance of 500-600 feet from the boundary of the fill (Figures III-24 and III-25).

The gas control system designed for this site consists of a trench, two to four feet wide and 10 feet deep to be excavated along the western boundary of the fill. The lower 6 feet of this trench is to be filled with No. 2 gravel. A four-inch perforated pipe is placed in the gravel layer about three feet from the bottom and two-inch risers are connected at 300-foot intervals, extending to the ground surface. Gravel is covered with an asphalt liner similar to the one used at Site No. 5 and the remainder of the trench is backfilled with soil excavated from the trench. Provisions are to be made for adequate surface drainage near the trench to prevent flooding of the gravel layer. One "tiki" burner will be connected to the riser at one end of the trench and all other risers will be plugged.

During a monitoring period other arrangements of burners and air inflow pipes should be investigated to determine the arrangement under which this control system would be most effective in intercepting the flow of gases beyond the trench. Layout plan and detailed design drawings for the control system at Site No. 8 are shown in Figure V-9.

The degree of effectiveness of this control system should be evaluated under the following program:

(1) Develop contours of equal methane concentration by sampling the probes installed around this landfill under a continuation of the gas sampling and analysis program. Comparison of

these contours with the ones developed under the gas sampling program of this year's study will provide a basis for determining control system efficiency.

(2) Additional probes can also be installed at 5 and 10 feet depth and at 200 foot intervals on both sides of the trench. If the control system operates effectively then methane concentrations on the fill side of the trench will be considerably higher than those on the opposite side.

DEVELOPMENT OF A DEVICE FOR MEASURING UPWARD MOVEMENT OF METHANE THROUGH SANITARY LANDFILLS

A sensor was developed for measuring upward movement of methane through landfill covers. This equipment consists of an adjustable probe and a gas explosive meter. The adjustable probe was built from a 22 calibre gun barrel about two feet long; a cross section of the probe is shown in Figure V-10. With this device an approximate concentration of methane can be detected at various depths between 0-2 feet. The advantage of this equipment rests in the possibility of making quantitative methane determinations at any desired depth (less than 2 feet) by inserting a single probe to the designated level. This probe can also be used to measure gas pressure in soil by connecting the sampling outlet to a U tube water manometer. A knowledge of concentration gradient and gas pressure, and a knowledge (or assumption) of the soil cover diffusion-dispersion coefficient enables the calculation of flow of methane through landfill covers. Tests of the effectiveness of this sensor are currently being made, and the results of such tests will be reported in later reports.

DISCUSSION OF DESIGN CONSIDERATIONS RELATED TO GAS MOVEMENT IN SOILS

In the design of new sanitary landfills, detailed soil information should be obtained for soils surrounding the proposed landfill site. This information should include the following:

(1) Particle size distribution

(2) In place density

(3) In place porosity

From the particle size distribution one can observe the relative proportion of various particle sizes in a soil sample. Information on in-place density and porosity aid in determining the degree of compaction of the natural soil around a proposed landfill site. The above information should be developed for various soil strata at the proposed site so that, based on these data and using the results of the laboratory experiment, a determination can be made as to the gas permeability characteristics of soils at the site under consideration. From particle size distribution analysis it can be determined whether the soil at the proposed landfill site is in the range of the four soils used in the laboratory experiment. Then, based on density, porosity, and moisture content values, a decision can be made as to which laboratory test condition best resembles the existing natural conditions at the proposed landfill site. The rate of lateral flow of methane from the proposed landfill can then be calculated by obtaining the coefficient of diffusion-dispersion under various probable conditions of gas pressure buildup in the fill. If the conditions at a site do not coincide with any of the laboratory test conditions but fall in the range of these tests an approximate value for the diffusion-dispersion coefficient can be obtained by interpolating between the two conditions which come closest to that of the case under consideration. It should be emphasized that the range of the brief laboratory experiment carried out under this study was not of such a breadth to enable evaluation of all possible conditions. This experiment was concentrated on four soils which cover a modest range among the infinite possible conditions that can be encountered in the field.

If the soils around a landfill site are mainly composed of fine clay and silt material, and especially if they contain adequate moisture (optimum moisture may be considered as a satisfactory level of moisture content), in all probability they will act as a natural barrier to gas movement. In order to alleviate a possible buildup of gas pressure in the landfill, construction of a gas venting system should be considered. Such a system in its simplest form may consist of a gravel layer of reasonable width which would be formed around the fill during the landfilling operations. The width of this layer is not a crucial parameter and it can be minimized to reduce the cost of the operation. The purpose of the gravel layer is to provide an easy outward passage for gases generated in the refuse fill. These gases can be collected through a perforated pipe of proper size which would be installed in the gravel layer before the final cover is placed. Gas collected in this pipe can be disposed of by discharging into the atmosphere, by burning or other methods.

A more sophisticated variation of the above system would encompass the installation of from 4 to 6-inch perforated pipes at 50 to 100-foot intervals on the sloping side of the fill. These pipes can be connected to a headpipe which would be buried under the final fill cover and which would transport gas to burners or other facilities for disposal or use.

If the conditions in a proposed landfill are conducive to generation of considerable volumes of leachate (possibility of frequent flooding, disposal of refuse with high moisture content, etc.) then provisions should be made for collecting and disposing of this leachate. Leachate in the fill can be collected into a sump in the center or in a corner of the fill from where it would be pumped. The fill bottom should be graded in a manner that leachate can flow in the direction of the sump. Dimensions and the number of sumps will depend on the size of the fill and frequency of pumping from the sump.

FEASIBILITY OF CONSTRUCTING SOIL MEMBRANES

When a landfill is to be constructed in gravel pits or natural depressions surrounded by coarse soils, which provide easy passage for gases generated in the fill, a gas barrier membrane should be provided for the fill. A variety of materials such as asphalts, polyethylene lining, etc., can be used for gas barrier membranes. However, high initial cost and the difficulty in protecting the membrane during filling operations renders these materials undesirable for large scale operations. Natural soils, on the other hand may be obtained at a lower cost than any of the above materials. It is therefore, recommended that a layer of fine clay-silt or silty-clay soil be placed under and around the landfill. This soil layer should be placed at optimum moisture and should be compacted to 90 percent or better of the maximum density at optimum moisture content. The minimum thickness of the fine soil layer is from 3 to 4 feet. However, compacting equipment, presently used for earth work involving quantities of earth contemplated for this operation, requires a minimum width of 10 feet for efficient operation; sidewall barriers would be, therefore, thicker than bottom barriers. In addition, a venting system should also be provided to prevent excessive pressure buildup in the fill. The gas disposal technique should be designed to eliminate problems associated with odor generation in the fill. Implementation of both a barrier and venting system should proceed with the filling operations.

CHAPTER VI

THE EFFECTS OF SANITARY LANDFILLS ON GROUND WATER QUALITY

HISTORY

The operation of controlled sanitary landfills has been practiced in the Los Angeles area since 1949. One of the prime concerns of the controlling agencies has been the prevention of groundwater pollution. This concern is reflected in Resolution 55-1 issued by the Los Angeles Regional Water Quality Control Board (a State of California agency) which classifies waste disposal sites and specifies the type of materials that are acceptable at each class site. The pertinent provisions of this resolution are quoted below:

"A. CLASSIFICATION OF DISPOSAL SITES

From consideration of the geology, hydrology, topography, nature of wastes and other pertinent factors, three general classes of disposal sites are established:

(a) CLASS I DISPOSAL SITES

Sites located on nonwater-bearing rocks or underlain by isolated bodies of unusable ground water, which are protected from surface runoff and where surface drainage can be restricted to the site or discharged to a suitable wasteway, and where safe limitations exist with respect to the potential radius of percolation.

(b) CLASS II DISPOSAL SITES

Sites underlain by usable, confined, or free ground water when the minimum elevation of the dump can be maintained above anticipated high ground water elevations, and which are protected from surface runoff and where surface drainage can be restricted to the site or discharged to a suitable wasteway.

(c) CLASS III DISPOSAL SITES

Sites so located as to afford little or no protection to usable waters of the state.

"B. NATURE OF WASTES ACCEPTABLE FOR DISPOSAL AT EACH CLASS OF DISPOSAL SITE

This list is not intended to be complete or comprehensive but rather an indication of the nature of wastes acceptable at each class of disposal site. Materials, other than those listed, may be considered separately by the interested governmental agencies and this Regional Water Quality Control Board.

(a) CLASS I DISPOSAL SITES

No limitation as to either solid or liquid wastes.

(b) CLASS II DISPOSAL SITES

Limited to ordinary household and commercial refuse and/or rubbish, garbage, other decomposable organic refuse, and scrap metal of the nature indicated below at safe elevations above anticipated high ground water elevation in the vicinity of this site:

(a) Empty tin cans
(b) Metals
(c) Paper and paper products
(d) Cloth and clothing
(e) Wood and wood products
(f) Lawn clippings, sod, and shrubbery
(g) Hair, hide, and bones
(h) Small dead animals
(i) Roofing paper and tar paper
(j) Unquenched ashes mixed with refuse
(k) Market refuse
(l) Garbage
(m) All materials acceptable at Class III Disposal Sites without regard to elevation of anticipated high ground water.

(c) CLASS III DISPOSAL SITES

Limited to nonwater soluble, nondecomposable inert solids of the nature indicated below:

(a) Earth, rock, gravel, and concrete
(b) Asphalt paving fragments
(c) Glass
(d) Plaster and plaster board
(e) Manufactured rubber products
(f) Steel mill slag
(g) Clay and clay products
(h) Asbestos shingles

"C. SPECIAL CONSIDERATIONS

Disposal sites in the alluvium which fans out from the mouths of major canyons and in such alluvial portions of the Los Angeles and Montebello forebay areas as may be critically located with respect to potential pollution, in the South Coastal Basin within the Los Angeles Region, should be restricted to Class III Disposal Sites, unless it can be

> satisfactorily demonstrated that the disposal of decomposable wastes will not cause a pollution or threat of pollution to any waters of the state.
>
> "D. APPLICABLE LAWS AND ORDINANCES
>
> All Federal, State, County and City sanitary and health codes, rules, regulations, laws, and ordinances pertinent to the disposal of wastes on land shall be complied with in the operation and maintenance of waste disposal sites."

All of the sanitary landfills in the Los Angeles area are required to operate in accordance with the above or similar resolutions.

It should be emphasized that solid waste disposal in sanitary landfills has very infrequently been associated with water pollution. The work conducted during this research program indicates that the above mentioned regulations are adequate to prevent water pollution. Efforts to find evidence of bacteriological or mineral impairment of ground waters in the vicinity of the research sites were unsuccessful with one exception which is discussed later in this chapter.

POTENTIAL WATER IMPAIRMENT FROM SANITARY LANDFILLS

The presence within a sanitary landfill of decomposable refuse, various liquids of an undesirable quality which may be trapped in the pores of the fill, and soluble fractions within the solid waste material, constitute a source of potential ground water impairment. These components, or products from processes acting upon them, may effect the ground water quality if methods of transfer are present to bring the contaminant and ground water body in contact with each other. The contaminant may be in leachate or gas form.

Presence of Leachates

The process of leaching is defined as the solution of a component from a solid mixture by a liquid solvent (Reference 8). For the purposes of this study the entire mass of refuse within a sanitary landfill can be considered as the solid mixture and water as the solvent. There are a number of ways by which water may enter a landfill. These include:

(1) Water applied to the surface and percolating vertically through the soil cover.

(2) Water from an adjacent source moving horizontally through the side of the fill.

(3) Water entering from the bottom of the fill due to a rise in the ground water table or capillary action.

(4) Water being present in the fill site prior or during placement of refuse material.

A necessary condition for impairment of water outside the limits of the landfill would be supersaturation of those portions of the fill in contact with the water. The moisture retention capabilities of the solid wastes must be determined in order to predict the amount of water required for saturation. It should be noted that it is not necessary to saturate the entire landfill to produce a leachate, particularly in the case where water enters the fill from below. The effect of capillary action within the solid wastes will also influence the degree of saturation in the fill.

Little information has been found with respect to the actual moisture holding capacities of landfills. However, during a field percolation study for the State Water Quality Control Board (Reference 9), Merz determined that 320 gallons of water were required to saturate a test bin. The test bin initially contained 11.1 cubic yards of domestic rubbish, including garbage, taken from city collection trucks and hand-tamped in 1-foot-thick layers. During packing operations, cans, bottles, cardboard boxes, and large pieces of miscellaneous material were rejected. Before any water was applied to the bin the volume had been reduced by settlement to 8.1 cubic yards. Based on the latter figure, the moisture retention ability of the test material is calculated to be 39.5 gal/cu yd (gallons per cubic yard). It should be pointed out that the test bin study was undertaken due to the inability to obtain adequate information on the conditions within a completed landfill.

The above tests were run on refuse which can be assumed to be representative of domestic refuse at the time (1954) for the area in which the tests were conducted. The composition of rubbish will vary greatly from one area to another depending on collection practices, climatic season and other factors. Typical compositions of refuse for summer months of various areas during the year 1954, showing the possible variations in composition, are given in Table VI-1.

TABLE VI-1

TYPICAL RUBBISH COMPOSITIONS FOR SUMMER 1954

Item	Composition - Percent by Weight			
	New York (Reference 9)	Signal Hill* (Reference 9)	Pasadena** (Reference 9)	Torrance** (Reference 10)
Garbage	43.8	42	0	0.5
Paper and Cardboard	25.5	21	30	30.2
Wood	5.9	5	10	1.9
Metal	6.6	--	--	1.0
Glass	6.3	--	--	
Grass and Leaves	1.1	31	60	64.1
Rags	1.8	--	--	1.0
Ashes	7.8	--	--	--
Miscellaneous	1.2	1	0	1.3

* Separate pickup of cans and bottles.
** Separate pickup of garbage, cans and bottles.

The practice of separate collection has now generally disappeared in the Los Angeles area and the refuse of today has considerably more paper and rags, greater than 40 percent, and less garbage. Also, the increase of nondegradable materials such as metals, glass, plastics, etc., is remarkable; from about 20 percent in 1954 to 46 percent in 1966 (References 11 and 12). From the above, it can be seen that the moisture-holding ability of refuse will probably vary from one landfill to another and also will probably vary from section to section within a given landfill. The extent of this variation has not been determined.

Leachate Composition

There is no general way to forecast the exact composition of leachates which may be associated with a landfill. Factors which are believed to influence the characteristics of a leachate are:

(1) Material in the fill (organic, inorganic, degradable, nondegradable, soluble, insoluble).

(2) Conditions in the fill (temperature, pH, moisture, age of fill).

(3) Characteristics of incoming solvent water.

(4) Surrounding soil characteristics.

The variation in composition of leachates from several sources is shown in Table VI-2. It should be noted that age of the refuse varies considerably with the samples shown. The refuse in the test bin sample was about 3 months old and the leachate sample given represents the high point during the percolation experiment (Reference 9). The refuse from which the Site No. 8 sample was taken is estimated to be about 10 years old and represents the other end of the scale.

To focus on the magnitude of or the potential amount of material which may be leached from a landfill, the following excerpt from the summary of the investigation by the University of Southern California (Reference 9) is useful.

> "It may be expected that continuous leaching of an acre-foot of sanitary landfill will result in a minimum extraction of approximately 1.5 tons of sodium plus potassium, 1.0 tons of calcium plus magnesium, 0.91 tons of chloride, 0.23 tons of sulfate and 3.9 tons of bicarbonate. Removals of these quantities would take place in less than one year. Removals would continue with subsequent years, but at a very slow rate. It is unlikely that all ions ever would be removed."

Changes in Leachates

During the course of percolation, leachates from landfills will change in chemical and biological composition; however, little information is available concerning this subject. The leachate sample from the Site No. 11 test well (Table VI-2) shows a marked reduction in mineral content, BOD, and COD after passing through 50 feet of soil when compared to leachate samples taken from test fills. A number of studies have been made regarding the reclamation of waste water by spreading in surface basins and the potential of this procedure for ground water pollution. These studies may not be entirely applicable due to the fact that they are dealing with conditions of percolation near the surface of the ground and are operating generally under aerobic conditions. However, they are discussed here because of the similarity of the processes involved.

TABLE VI-2

ANALYSIS OF LEACHATES FROM LANDFILL REFUSE

	Source of Sample			
Determination (ppm)	Test Bin* (Reference 9)	Site No. 2 Test Fill* (Reference 13)	Site No. 8 Test Well**	Site No. 11 Test Well***
pH	5.6	5.9	8.3	7.2
Total Hardness as $CaCO_3$	8120	3260	537	1540
Calcium	2570	905	72	302
Magnesium	280	254	87	192
Iron, total	305	33.6	219	2.0
Sodium	1805	350	600	69
Potassium	1860	655	NR	13
Boron	NR	7.13	Nil	1.15
Sulfate	630	1220	99	615
Chloride	2240	NR	300	NR
Nitrate	NR	5	18	NR
Alkalinity as $CaCO_3$	8100	1710	1290	974
Ammonia Nitrogen	845	141	NR	0.3
Organic Nitrogen	550	152	NR	2.1
COD	NR	7130	NR	36
BOD	32400	7050	NR	Nil
Total Dissolved Solids	NR	9190	2000	1960

NR = No Result
* Sample from sumps at bottom of test fills
** Sample of water found in refuse during drilling of test well
*** Sample from test well located 50 feet from large refuse fill

The natural cycle of self purification by percolation through soil involves physical, chemical and biological systems which are inter-related and mutually dependent. It has been observed (Reference 14) that in the top three feet of an aerobic soil layer, COD loadings in citrus wastes may be reduced from 5,000 milligrams per liter to less than 100 milligrams per liter. A study by the University of California for the California State Regional Water Quality Control Board (Reference 15) concluded that a bacteriologically safe water can be produced from settled sewage or from final effluent if the liquid passes through at least four feet of soil. The term "bacteriologically safe" means capable of meeting the U. S. Public Health Service drinking water standards for the coliform group. The results obtained in another water reclamation study (Reference 16) did not agree with the above conclusion; however, it was concluded that in all probability, these (coliform) bacteria would be removed by deeper percolation or by lateral travel in the zone of saturation. These factors must be considered in order to properly view the pollution potential of the leachates that may leave a landfill and percolate through the soil.

If a leachate reaches ground water by some means, either direct or indirect, dilution of the leachate by the ground water may take place by two different ways (Reference 17):

(1) By mixing with adjacent ground water as it enters a well casing and is pumped out, and

(2) By dispersion into the adjacent ground water during flow.

The extent of this dilution is dependent on characteristics of both the leachate and the ground water body and are complex. No attempt is being made here to identify and evaluate all of the factors involved; however, Merz (Reference 9) has determined that,

> "Dissolved mineral matter, entering a ground water as a result of intermittent and partial contact of a sanitary landfill with the underlying ground water, will
>
> (a) Have its greatest travel in the direction of flow.

"(b) Undergo a vertical diffusion to a limited extent, and, where the aquifer is of appreciable thickness (100 feet or more), the bottom water will probably remain unimpaired.

(c) Be subject to dilution, the result of which will be a minimizing of the effect of the entering pollutant ions."

"Where the pollutional load on a ground water is light by reason of a sanitary landfill being in intermittent and partial contact with the underlying ground water, the most serious impairment of the ground water as little as a half-mile downstream from the landfill will be an increase in hardness, and then only in the upper portions of the aquifer."

Gas Production

A number of gases associated with decomposition processes within a sanitary landfill have been observed or suspected. These gases include: carbon dioxide, methane, nitrogen, oxygen, hydrogen and hydrogen sulfide. The composition of gas samples produced from landfill refuse under various conditions is given in Table VI-3. All samples, except sample D, are from test cells constructed to study factors involved with sanitary landfills and represent extreme conditions.

Hydrogen and hydrogen sulfide have not been found in any great extent in sanitary landfills. Samples of gases produced by a test fill in Azusa showed early concentrations of hydrogen as high as 14.1 percent (Reference 20); however, this soon decreased and methane concentration increased. Hydrogen sulfide would not be expected in significant quantities unless water containing high concentrations of sulfate, such as sea water, was present in the refuse. The gases produced by decomposition that are most prevalent, and of most concern, are carbon dioxide and methane. From test fill studies it has been estimated that over 90 percent of the gas produced by refuse decomposition in large landfills is carbon dioxide and methane (Reference 21).

Decomposition processes within a sanitary landfill are carried out through the action of bacteria and other microorganisms on the organic refuse material. Gram (Reference 17) has represented the decomposable refuse by the empirical formula:

$$CH_aO_bN_c$$

TABLE VI-3

COMPOSITION OF GASES PRODUCED FROM LANDFILL REFUSE UNDER VARIOUS CONDITIONS

	Composition (percent)				
Designation*	A (Ref. 9)	B (Ref. 18)	C (Ref. 18)	D	E (Ref. 19)
Age of Refuse	.33 years	873 days	852 days	3 to 4 years**	1238 days
Depth Below Surface	6 ft	15 ft	15 ft	4 ft	13 ft
Carbon Dioxide	38.2	44.30	28.00	33.3	6.24
Methane	46.5	55.60	0.84	32.6	3.87
Nitrogen	14.9	0.04	70.06	27.4	73.02
Oxygen	0.4	0.60	0.89	0.6	16.87
Hydrogen	NR	0.0	0.21	NR	0
Hydrogen Sulfide	NR	Trace	Trace	NR	NR

* Notes on designated samples:

A - Samples from percolation bin constructed for leaching study and saturated with water.

B - Sample from test cell saturated with water at time of construction.

C - Sample from test cell where no water was added at time of construction.

D - Research Site No. 5 test probe (27c) installed for this study in conjunction with Greenhouse Gas Control System.

E - Sample from test cell constructed with air ducts beneath the fill through which air is forced.

** Estimated

NR = No Result or Not Tested

If oxygen is present in the environment, decomposition will proceed by aerobic processes which are represented by the chemical equation:

$$CH_aO_bN_c + 1/4\ (4+a-2b-3c)O_2 \longrightarrow CO_2 + 1/2\ (a-3c)H_2O + cNH_3$$

In the absence of oxygen, anaerobic decomposition will take place which may be represented by the following overall chemical equation:

$$CH_aO_bN_c + 1/4(4-a-2b+3c)H_2O \rightarrow 1/8(4-a+2b+3c)CO_2 + 1/8(4+a-2b-3c)CH_4 + cNH_3$$

Since oxygen is available within the refuse when it is first placed, the initial decomposition will be aerobic, but unless diffusion and convection provide adequate mixing of the internal and external atmospheres, the oxygen in the interior of the fill will be depleted and thereafter the decomposition will proceed anaerobically.

The mechanism of anaerobic fermentation in a landfill consists of two consecutive steps; carbohydrates are broken down to organic acids by various saprophytic organisms and, in subsequent biochemical relations, these acids are converted to carbon dioxide and methane. As in anaerobic sewage sludge fermentations, cells will be continuously produced and destroyed by the metabolic processes. Most of the nutrients, the most significant being nitrogen, are cycled through successive generations of microorganisms. The quantity of available nitrogen increases slowly as proteins are broken down.

The process of fermentation may be very slow until the time when nitrogen is no longer a limiting factor. Because water is necessary for enzymatic activity and to transport growth limiting material within the fill, the moisture content in a fill is of major importance. Refuse in a dry fill will decompose at a much slower rate than in a wet fill.

Gas Solubility

The process by which gases are dissolved in water is known as absorption and involves the transfer of gas from the gas phase into a liquid, in which it is more or less soluble (Reference 23). Nearly all gases are soluble in water to some degree although in many cases this solubility is very slight. The solubilities of various gases associated with landfills are given in Table VI-4. The values given represent saturated conditions.

Gas absorption is a diffusional operation. The rate at which the gaseous constituent of a mixture will dissolve in an absorbent liquid depends upon the departure from equilibrium which is maintained; thus the manner in which the liquid and gas are brought into contact with each other is of great importance. In addition, the degree of chemical reaction between the gas and liquid will have its effect on absorption rate.

TABLE VI-4

SOLUBILITY OF GASES ASSOCIATED WITH LANDFILLS IN WATER

One Atm. 20°C

Gas	Solubility, mg/l
Carbon Dioxide	1,688
Methane	60.1*
Oxygen	43.4
Nitrogen	19.0
Hydrogen	1.6
Hydrogen Sulfide	3,846

* Calculated

Source: Reference 22

Of the gases which may be produced in a sanitary landfill, carbon dioxide is the only one with a high degree of solubility present in large quantities. As gas is produced within the fill, it will move away from the source of production in various directions by pressure gradient, convection and diffusion processes. During studies of a test fill (Reference 13), it was found that 23½ times as much carbon dioxide was passing through a one-foot silt cover to the atmosphere than was passing through the sides and bottom of the fill.

Once the gases have penetrated into the surrounding ground they will continue to move by convection and diffusion. Gas mixtures heavier than air will fall and spread laterally, becoming mixed with the soil atmosphere. As the gas travels through the soil it will come into contact with the soil moisture and, if soil permeability permits, with the ground water table and capillary fringe.

The actual mechanism by which carbon dioxide is absorbed into water from a gas stream moving to the ground water table is complex and would seem to be inefficient when viewed as an absorption process. One would expect, however, that water percolating through a refuse landfill to produce leachates would also come in contact with large amounts of carbon dioxide within the fill atmosphere and a relatively effective absorber would be in operation. The ability of the leachate to absorb carbon dioxide may be reduced to some degree by the presence of leached salts already dissolved, but this would diminish as salts are removed from the fill.

EFFECT ON GROUND WATER

Free carbon dioxide is undesirable in water supplies in that it will increase the corrosiveness and aggressiveness of water (Reference 24). Dissolved carbon dioxide reacts with water to form carbonic acid,

$$CO_2 + H_2O \rightleftharpoons H_2CO_3$$

which in turn dissociates to form bicarbonate ions,

$$H_2CO_3 \rightleftharpoons H^+ + HCO^-_3$$

If solid calcium carbonate is present within the soil, carbonic acid will react with it to form soluble calcium bicarbonate. The overall reaction would be:

$$CaCO_3 + CO_2 + H_2O \rightarrow Ca^{++} + 2HCO_3^-$$

When this reaction takes place in the presence of free carbon dioxide, the carbon dioxide removed from the water leaves room for more to dissolve and the process continues until an equilibrium is obtained. The resulting increase in calcium hardness is the principal undesirable effect associated with carbon dioxide [illegible] ground water, although the process will reverse itself when the ground water flows to a region where the soil atmosphere is low in carbon dioxide.

As in the case with leachates, water that has been impaired by carbon dioxide will be diluted within the ground water body. It is difficult to determine the origin of water impairment because of this dilution and the fact that a combination of sources may be involved.

PROJECT INVESTIGATION

One of the research sites chosen for this study, No. 8, is adjacent to a water well which has had a history of impaired water quality. The dump site has been thought to be responsible for this impairment and has been the subject of a number of studies. Research site No. 8 was an abandoned gravel pit located on a broad alluvial cone which extends from the nearby mountains.

In 1955, a resolution was adopted by the Los Angeles Regional Water Quality Control Board requiring the applicant to fill the pit with inert solid fill (Class III) up to an elevation of 325 feet, which is five feet above anticipated high ground water. Rubbish was then permitted above this elevation.

During February 1958, taste and odor problems developed within the water system of the local water company. Musty taste and odors were intermittently found within the service area of the well. The company investigated this problem, discontinued use of this well, and no further complaints were received.

The water company contacted the Regional Water Quality Control Board and an investigation was undertaken. The localized nature of the ground water impairment indicated a local source and the presence of both recent and historic dumps in the vicinity were potential causes. The Site No. 8 operation was the nearest, being within 400 feet of the well.

The Regional Water Quality Control Board then requested the California State Department of Water Resources to investigate this problem. The Board had previously adopted a policy of restricting the dumping of decomposable rubbish to an elevation higher than the anticipated maximum ground water elevation and to cause surface runoff and flood waters to be diverted from the dump site. Since it was believed that the Site No. 8 operation was in accordance with this policy, the need for new criteria for establishing waste discharge requirements for refuse disposal sites had to be considered.

The Department of Water Resources completed its investigation in October 1961. Investigations included the placing of well points, obtaining samples of gas and water for analysis, and preparation of a full report (Reference 25). The findings and conclusions of the Department were that the ground waters of the water basin are generally of excellent mineral quality; however, there has been a history of water quality impairment by carbon dioxide in some wells within the basin which were perforated at depths less than 150 feet. Carbon dioxide was found in the alluvium above the impaired ground waters and Site No. 8 operation was a source of carbon dioxide and methane. The period of greatest water quality impairment directly followed the two wettest years since 1950. The impairment of the well was primarily due to solution of carbon dioxide gas and the major source of carbon dioxide in the vicinity of the well was the decomposing refuse in the Site No. 8 operation.

The findings and conclusions of the Department of Water Resources were based on the assumption that the filling operation was carried out as required by the Regional Water Quality Control Board. No apparent effort was made to determine the maximum depth of refuse placement. One test well was placed over rubbish fill in the northwest portion of the site which revealed decomposed material to elevation 319 feet, six feet below the allowed elevation. However, no other test wells were drilled within the site. The location of the Department test well is shown on Figure VI-1. Additional studies, made since the original Department report, have not included determining the extent of refuse placement.

RECENT FINDINGS

Information was found during this research which may clarify some of the studies performed on Site No. 8 to date and may influence future work. One item of interest is a topographic map of the original dump site and spreading basin made in 1954, one year before dumping operations started. It is believed that this map represents the original pit much more accurately than the small scale U.S.G.S. quadrangle sheet which was then available. The portion of the original pit underlying Site No. 8 is reproduced on Figure VI-1.

Recently, in response to a request from an operator who was proposing a landfill operation in another area, a private engineering geologist had several test borings made within the site. Because the topographic map mentioned above was not yet available, the location of the test borings were determined by the U.S.G.S. quad sheet and by verbal information supplied by persons familiar with the dumping operations. The location of the test borings is shown on Figure VI-1. While an attempt was made to place some of the holes in the deepest portion of the original pit, the rough surface terrain and limited time and funds prevented placing all the holes desired. The results of the test borings are shown in Table VI-5.

All of the test holes except B-1 showed large amounts of water within the rubbish. Test hole B-3 showed extreme amounts of water below 12 feet (elevation 329.2) and the hole had to be abandoned at 30 feet (elevation 311.2), while still in rubbish, due to the excessive water. All of the test borings showed decomposable rubbish below the allowable elevation of 325 feet. Cover material was found to be at least five feet deep at all holes.

The material found at the bottom of each hole completed was, in the opinion of the geologist on the site, typical of the material found in the original pit. It was his opinion that little, if any, solid fill was placed beneath the rubbish at the test boring locations. The relation of the test borings findings to the original pit as found on the 1954 map is shown in Figure VI-2. The relation of the Site No. 8 dump to the well and the spreading basin is shown in Figure VI-3.

This recent information seems to indicate that the water quality degradation of the well was caused by one or more of the following reasons:

(1) Surface water from adjoining areas was allowed to flow onto the rubbish fill and percolate through the fill to the underground water supply.

TABLE VI-5

RESULTS OF TEST BORINGS AT RESEARCH SITE NO. 8
1968

Allowable lower limit for decomposable rubbish = Elev. 325'

	Elevations (feet)			
Test Hole	Surface	Rubbish Limit	Pit Bottom*	Hole Bottom
B-1	346.7	322.7	323	297.7
B-2	344.5	320.5	314	313.5
B-3**	341.2	Unknown	299	311.2
B-4	340.5	304.5	307	285.5
B-5	343.4	297.4	298	289.4

* Estimated from Plan

** Hole abandoned due to excessive water in hole.

(2) Rubbish placed below the high ground water elevation was saturated by the adjacent spreading grounds and the resulting leachate was forced in the direction of the well.

(3) The high moisture content of the rubbish caused rapid decomposition and resulted in excessive amounts of carbon dioxide which then mixed with the underground water.

The actual cause of water quality degradation probably lies with a combination of all the above mentioned factors.

CHAPTER VII

COMPLETED SANITARY LANDFILL LAND USES

Although the land uses of completed sanitary landfills are to be studied in detail during the second year of this project, a preliminary investigation of uses was undertaken during the course of the first year study to point up the variety of such uses for completed sanitary landfills in the Study Area. These land uses include:

(1) Athletic fields
(2) Botanic gardens
(3) Golf courses
(4) Golf driving ranges
(5) Parks
(6) Parking lots
(7) Play grounds
(8) Salvage and storage yards
(9) Commercial and industrial buildings
(10) Trailer parks

Certain sites and their current uses are reported upon herein to demonstrate the magnitude of the damage to improvements that can result from construction on or adjacent to poorly constructed landfills if precautions are not taken relative to the contemplated use.

SITE NO. 4

This site is a canyon fill which was completed in 1961. A trailer park was constructed on terraced areas adjacent to the fill, with sewage collection facilities, septic tanks, and leaching lines constructed over the rubbish fill. Saturation of the fill with sewage has caused extensive settlement in the area. There is some evidence that part of the trailer park was constructed on the fill and, with the settlement which has taken place, many of the trailer slabs have been destroyed. Roadways in the area have settled badly causing numerous cracks and requiring constant repairs. Many of the utility lines have been broken and replaced. A trailer manufacturing company, also located adjacent to the fill, has lost some of its parking lot area and an office building has had to be moved to an area outside the fill limits. Much of the asphalt pavement has cracked throughout the area where it was laid on the landfill. A discussion of the extent of gas movement in the areas around the landfill and the method of control used to alleviate this problem was presented in Chapter III. A picture of this site is shown in Plate F.

SITE NO. 8

This site is a prime example of what can happen to structures built on completed landfills which have been poorly constructed or have been subjected to conditions which cause excessive settlement. A portion of the site was used as a trailer park until abandoned during this study period. Structures built on the site include a clubhouse, an office building, service buildings, and a swimming pool. All buildings were constructed on concrete slabs. Considerable differential settlement in the trailer park area has taken place resulting in the complete loss of the swimming pool and the clubhouse. Other structures were badly damaged. Streets have settled, causing overall drainage problems, and utility lines have had to be repaired several times.

The structures at this site are generally of standard wood frame and stucco construction with rocked roofs. A picture of the site prior to abandonment of the trailer park is shown in Plate K.

OTHER SITES

One landfill site, not included among the fills selected for the purpose of this study, is presented here as an example of a multipurpose use of completed landfills.

This fill was a very large operation covering an extensive area. At present, a few structures have been constructed on the fill. A golf course, restaurant, and garages are located on the northerly portion of the fill. Considerable settlement has occurred in the golf course area and many of the concrete slabs supporting vending machines and similar equipment have been broken and are badly tilted. The restaurant was constructed on piles, placed through the fill and appears to be in good condition. However, settlement in the parking lot area is quite evident. The garages are located on fill but were constructed as separate units to allow for differential settlement. These wood frame buildings are on concrete slabs and have undergone some settlement but are still in fairly good condition and are being used.

Construction on another site, not studied in detail during this project, is presented as an example of the use of landfills for commercial buildings.

Upon completion of the fill, a large retail store building and an asphalt parking lot were constructed on the site. The building is constructed of grouted brick masonry walls with a panelized wood roof supported by tapered steel girders bearing on interior pipe columns and exterior bearing walls. Each interior column is supported by a single concrete pile driven through the refuse fill to the natural soil. The exterior masonry walls are supported on reinforced concrete grade beams spanning between concrete piles driven around the periphery of the building. The interior floor slab was poured on a gravel base laid on top of the refuse fill. Provisions were made at each interior column and at the exterior walls for floor slab settlement, with a maximum anticipated settlement of two feet. Provisions were also made for venting the floor slab base material to the outside walls of the building to prevent any build up of gases escaping from the landfill.

A six-inch steel fire line, buried in the ground and supported by hangers anchored to one of the exterior walls of the building, broke because of the failure of the hangers to support the line after settlement of soil beneath the line. This caused flooding of the fill which resulted in an immediate settlement of the landfill beneath the floor slab varying from zero to 2.5 feet. The provisions incorporated in the design of the building to allow the floor slab to settle failed at all locations, causing failure of the floor slab, pile cap tie beams, and the pile caps. Extensive remedial repairs were required, including removal and replacement of large portions of the floor slab and most of the pile caps along one side of the building. There have been no visible signs of failure in the pipe columns, walls, or roof framing.

CHAPTER VIII

CODE CONSIDERATIONS FOR CONSTRUCTION AND USE OF SANITARY LANDFILLS

Increasing demand for land in metropolitan areas is augmenting the use of property located on or adjacent to completed sanitary landfills. In order to insure the safety of buildings and personnel careful consideration should be given to the development of a Code for construction of sanitary landfills and any structures which might be constructed on the surface of the fill. The Code should include areas adjacent to landfills if no positive steps are taken to prevent gas movement. Hazards to life and property could result from unequal settlement and the accumulation of combustible refuse gases.

The general public, as well as most individuals concerned with building construction, is not fully cognizant of the extent of hazards which can be created by gases generated in a refuse fill. While there is considerable awareness of the dangers from natural gas pipelines, the experience of public and private agencies with gas migration from a refuse fill is limited.

Based on data now known, safety measures for protecting a building from possible refuse gas hazards should be comprehensive and broadly based. These measures should take account of the fact that production of methane in a refuse fill may continue for several decades and may not begin for several years after the completion of the fill (depending on the construction and environmental conditions of the fill area). Any structure constructed on a completed refuse fill should be designed to prevent the accumulation of combustible gases, either by construction of an adequate ventilation system or an impervious membrane. Similar precautions may be necessary on areas adjacent to the fill. Surveillance of these structures is necessary to assure that safety measures are not ignored due to changes in the uses of the structures. Carefully planned land use of filled areas, standardized refuse fill practices, and adequate building codes appear to be reasonable requirements for the public's protection.

At present, building codes recognize, to a limited extent, the hazard from gas to buildings placed upon refuse fills but the structural problems due to settlement usually receive more consideration. In general, little or no attention is given to the potential gas hazard for buildings located upon undisturbed land adjacent to the fill.

The purpose of the following sections is to review some of the current building code requirements, to delineate areas where additional requirements may be needed, and to suggest some preliminary requirements which should be considered for refuse fill construction, subsequent land use, and building codes for construction on and adjacent to the fill.

LOS ANGELES COUNTY BUILDING CODE

The County of Los Angeles Building Laws (Reference 26) have for many years included some provisions for fills containing decomposable material. Section 308 (c) reads as follows:

> "Fills Containing Decomposable Material. Buildings or structures regulated by this Code shall not be constructed on fills containing rubbish or other decomposable material unless provision is made to prevent the accumulation of decomposition gases within or under enclosed portions of such buildings or structures and to prevent damage to structure, floors, underground piping and utilities due to uneven settlement of the fill. One-story light-frame accessory structures not exceeding 400 square feet in area nor 12 feet in height may be constructed without special provision for foundation stability."

The above restrictions do not at present apply to construction upon a site adjacent to a fill. The code further stipulates that the building official may require a geological or engineering report, where in his opinion such reports are essential for the evaluation of the safety of the site. This report is usually requested when there is the possibility of hazard to a structure from landslide, settlement or slippage. However, no such provision is made for submittal of a report on problems associated with gas production and movement from sanitary landfills. Consideration should be given to expanding this section to require an engineering report when such problems are expected.

There are no restrictions in the present code or zoning ordinance regarding the location of school buildings,apartments or other high occupancy structures adjacent to refuse fills. A thorough study of all conditions should be made before locating such structures adjacent to a refuse fill placed in porous soil material unless special provisions for control of gas movement are made.

GAS CONTROL AT COMPLETED REFUSE FILLS

Gas movement from completed landfills or refuse fills under construction constitutes a problem in that many of the older refuse fills, and some of the recent ones, are located in developing areas, and many structures are already built in the vicinity of these fills or are in the process of construction. Adequate gas control planning cannot be exercised in many of these cases and control measures may prove very costly. Gas control measures can, in most cases, be implemented during landfill construction at less cost than when the fill is completed.

For the case of completed landfills, it may be necessary to require gas control measures in connection with issuance of building permits. Such control would require that a gas movement survey be conducted at the site of fills to assess the present gas penetration and the potential gas penetration as well as the possibility of occurrence of any gas hazards. Where such possibility is shown, it would then be necessary to prevent the accumulation of gases in the structure.

The possibility of moisture entering a filled area should be examined in conjunction with gas movement evaluation. The introduction of a significant quantity of water to a fill, from either storm runoff, from the rupture of a sewer line or water main, or from rising ground water can result in biological activation of the fill and rapid decomposition. Increased gas production would occur under these circumstances, thus creating potential gas hazards where none may have previously existed.

Prior to the issuance of a building permit for structures to be constructed upon refuse landfills or adjacent to landfills where gas movement is suspected, an engineering report should be prepared by a qualified engineer. This report should contain recommendations which will provide for the safety of the proposed structures.

CONTROL OF FUTURE REFUSE FILLS

Results of this study and future research on the movement of methane through various soils will permit the evaluation of the gas movement problems for various potential fill sites. At fill sites where the gas permeability of the surrounding soil is very high it may be necessary to import gas barrier material for lining the bottom and sides of the fill. In such cases it may also be necessary to provide a venting system to dispose of the refuse-produced gases. The venting system should also provide for control of odor created by the gases. Such a gas control system will probably require a specific design for each new location, due to the many possible conditions that may be encountered. Future land use, location of any utilities, roadways, building construction problems, and possibility of flooding should be considered before fill construction is started.

All future refuse fill sites should be examined by an engineer experienced in this field and evaluated for establishing the technical soundness of the fill location before a use permit is issued. Furthermore, the land use zoning for both the fill area and any surrounding land that may conduct the refuse-produced gases outward from the fill should be established prior to issuance of a disposal permit.

CONTROL OF GROUND WATER QUALITY

In order to prevent potential pollution of an underlying ground water body, the following steps should be taken before a sanitary landfill is constructed in water-bearing sands and gravel formations:

(1) Surface drainage from adjacent tributary areas should be diverted from the site or carried in a lined channel or storm drain to prevent storm waters from entering the rubbish.

(2) Direct rainfall should be drained from the site by proper sloping of the surface and placement of a relatively impervious surface layer.

(3) All rubbish should be placed at least 10 feet above the anticipated high ground water level unless a suitable barrier is constructed to prevent the flow of ground water into the deposited

rubbish. Any barrier or liner should be designed for uplift pressures if it is constructed below the anticipated high ground water level.

A Code for the Construction and Use Criteria for Sanitary Landfills will be completed during the third year of this project.

CHAPTER IX

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

Chapter I - Introduction

The County of Los Angeles is conducting a three-year program of research and investigation for the development of construction and use criteria for sanitary landfills. Objectives of the first year program include: (1) a study of the existing state-of-the-art in construction and operation; (2) an evaluation of gas movement in certain existing sites; (3) review of literature regarding possible effects of sanitary landfills and ground water quality; (4) laboratory experiments for testing flow rate of gas through various soils; (5) development of solutions for controlling gas generated in sanitary landfills; and (6) field operations of gas sampling and analysis and settlement surveying.

Chapter II - Sanitary Landfill Practice

Construction and operation of sanitary landfills was reviewed as practiced by the City of Los Angeles, City of Burbank, County of Orange, County Sanitation Districts of Los Angeles County and private operators. Construction usually consists of the fundamental operations of: (1) selection of site in ravine, canyon or man-made pit; (2) deposition of rubbish in a systematic manner; (3) spreading and compaction of rubbish by tracked equipment and steel wheeled compactor; (4) containment of rubbish within cells; (5) daily cover of completed cells with a thin layer of soil, and (6) cover of completed landfill with a thick layer of soil.

Chapter III - Selection of Landfill Sites and Scope and Results of Studies

Eleven sanitary landfills were selected for study, and general soil and geologic information was obtained for these landfills. Ten of the sites were chosen to analyze gas production and movement. The eleventh site was used for settlement analysis only. A total of 338 gas probes were installed around these ten landfills with the majority of the probes being placed approximately three feet deep. Some were located at deeper depths, varying from 5 to 16 feet, because of particular soil conditions and/or the desire to analyze gas concentration at greater depths. In addition, a total of 50 probes, installed by others at certain of the sites prior to this study, were incorporated into the sampling schedule for this program.

A minimum of two series of samples were obtained and analyzed from these probes. Using the results of these analyses, contours of equal methane or carbon dioxide concentration were plotted around each landfill. Correlations were developed between the pattern and extent of gas movement and the nature of soil formations, the topography and the effect of existing gas control devices.

Survey monuments were established at four selected sites and background data was collated on land subsidence at these and at other sanitary landfills.

Chapter IV - Gas Movement Through Porous Media

Laboratory experiments were conducted to test the suitability of natural soils for gas barrier membranes. Four soils with different particle size distributions were separately tested in a laboratory diffusion column at two levels of moisture content and three inflow gas pressure conditions. Using an analytical solution for the differential equation governing the flow of gases through porous media, diffusion-dispersion coefficients for each soil were determined. These data provide a basis for calculating the rate of flow of gases through these soils under different conditions of soil moisture, compaction and gas pressure. This rate, in turn, provides a basis for determining the relative degree of effectiveness of these soils as gas barrier membranes.

Chapter V - Design of Field Gas Barriers and Control Devices

Field experiments on gas barrier and control devices were designed; these designs envision the implementation of gas control systems at three of the sites in the Los Angeles area. One of these systems (at Site No. 1) involves the excavation of five, 60 foot deep wells about 150 feet from the finished landfill. The deep well system will operate on the basis of combined gas suction and air flushing. Another control system (at Site No. 5) consists of an asphalt-type membrane installed under a greenhouse constructed directly upon the fill. A third system (at Site No. 8) involves the excavation of a 10 foot deep interceptor trench along one of the boundaries of the fill. This trench will be backfilled with No. 2 gravel and the intercepted gases transferred to a "tiki" burner through a horizontal 4-inch perforated pipe and vertical risers spaced at 300 feet intervals.

Chapter VI - The Effect of Sanitary Landfills on Ground Water Quality

Sanitary landfills may produce water quality degradation if proper construction practices are not followed. Water quality degradation can occur through: (1) percolating water carrying away liquids of undesirable quality which were contained within the fill; (2) percolating water dissolving undesirable waste fractions; and/or (3) gases generated within the fill diffusing downward and outward to be dissolved in ground water. The degree of degradation depends upon the quantity of waste generated and dissolved which, in turn, depends on such landfill conditions as type and state of fill material, physical and chemical conditions within the fill, surrounding soil characteristics and proximity of ground water.

Chapter VII - Completed Sanitary Landfill Land Uses

Land uses on completed landfills within the Study Area include athletic fields, botanical gardens, golf courses and driving ranges, parks, parking lots, playgrounds, salvage and storage yards, and trailer parks. Most of the completed landfills were fulfilling their purpose and have provided beneficial uses for the completed landfill property. Severe damage to surface structures and subsurface structures were observed in those landfills where either sound engineering practices were disregarded during construction of the landfill or no effort was made to design for differential settlement and the combustible gases produced in the landfill.

Chapter VIII - Code Considerations for Construction and Use of Sanitary Landfills

Existing regulations governing sanitary landfill construction and operation do not fully recognize dangers inherent in the subsurface production and movement of methane gas. This deficiency could be alleviated by requiring that a full investigation be made by a qualified engineer. Conclusions by the engineer should consist of an evaluation of methane production potential, possibility of methane movement into adjacent lands and recommended methods of control.

CONCLUSIONS

(1) Production of gases in a landfill is related to decomposition of the various materials placed therein. The amount of moisture present in the landfill greatly affects the rate of decomposition. Available data indicate that gas production and movement can take place many years after completion of a sanitary landfill.

(2) Gases generated in a sanitary landfill, consisting predominantly of methane and carbon dioxide, may travel a considerable distance from the fill, depending on the nature of the soil formations around the fill. Among the landfills selected for this study, methane concentrations of 10 percent were detected below the ground surface at a distance of 600-700 feet from the fill at Site No. 1 and 600 feet from the fill at Site No. 8. Both of these landfills were constructed in depressions resulting from gravel mining operations. The natural soils around these fills consist of coarse materials and are classified as gravelly sand. On the other hand, at Landfill Site No. 6 where the soil formations consist predominantly of fine materials such as silt and clay, shallow probes at a distance of 200 feet from the fill detected only negligible methane concentrations.

(3) Gas movement from sanitary landfills takes place by molecular diffusion and convective gas transport mechanisms. Positive gas pressures of from 2 to 3 inches of water have been registered in or adjacent to sanitary landfills. The rate of this transfer is determined by the permeability characteristics of the soil formations around the fill so that, for example, different flow rates may result, under identical pressure and concentrations, from two landfills, one in a gravel pit and another in a tight soil formation.

(4) The practical importance of the results of the laboratory experiment is that an effective gas barrier can be formed around landfills that are constructed in gravel pits by the construction of a membrane of fine textured soils under and around these fills. In the case of landfills which are constructed in areas where soils of sufficiently high clay or silt content predominate, there may be no need for installation of artificial membranes. Provisions for venting the landfill will assist in preventing buildup of gas pressure and reduce possible gas movement.

(5) Gas movement from sanitary landfills in this geographical area has not resulted in serious fire and explosion hazards to buildings located on the landfills and neighboring areas. In order to alleviate potential problems where gases are shown to exist by monitoring, steps should be taken to assure adequate venting under and in all buildings on or near the landfill so that explosive gases can not be trapped or accumulated in the buildings.

(6) Existing building codes do not recognize a need to protect structures, located adjacent to refuse fills, from the possible hazards of horizontal gas movement.

(7) Gas control measures, if required, would be easier to provide before or during construction of the landfill.

(8) Buildings, surface improvements, and subsurface structures can suffer extreme damage and destruction if constructed on sanitary landfills without proper regard for the potential differential settlement.

(9) Further research and study is needed to ascertain the seriousness of gas movement away from landfills and its effect on improvements and land use of adjacent areas.

RECOMMENDATIONS

The following recommendations are made as a result of work completed during the first year program:

(1) Comprehensive soils information should be obtained for the design of new sanitary landfills to evaluate the surrounding conditions and anticipate the movement of decomposition gases to adjacent areas. If significant gas movement is expected, consideration should be given to the design of a soil barrier to prevent movement of gases to adjoining property.

(2) The ultimate land uses of a proposed sanitary landfill should be established prior to the selection of the site and the construction of the landfill.

(3) In order to prevent pollution of an underlying ground water body, the following steps should be taken before a sanitary landfill is constructed over water-bearing sands and gravel formations.

  (a) Surface drainage from adjacent tributary areas should be diverted from the site or carried in a lined channel or storm drain to prevent storm waters from entering the rubbish.

  (b) Direct rainfall should be drained from the site by proper sloping of the surface and placement of a relatively impervious surface layer.

  (c) All rubbish should be placed at least 10 feet above the anticipated high ground water level unless a suitable barrier is constructed to prevent the flow of ground water into the deposited rubbish. Any barrier or liner should be designed for uplift pressures if it is constructed below the anticipated high ground water level.

(4) A program of gas monitoring should be undertaken at all completed landfills regardless of age since completion. This

monitoring could be performed using methane detection equipment of the type used by sewer maintenance agencies, fire departments, or gas distribution utilities. Results of this program should be brought to the attention of the building officials so that steps can be taken to prevent construction of buildings without proper precautions.

Methane gas production and movement can be detected by "sniffing" bar holes in the upper soils surface layer on and adjacent to completed landfills. Sewers and storm drains in the vicinity should also be checked for the presence of gas.

   (a) If gas is not detected, the monitoring should be repeated periodically and the site should be watched for signs of decomposition.

   (b) If gases are found, a more detailed study of the landfill and surrounding area should be made to determine the extent of gas movement and to evaluate the hazards, if any.

(5) Where sanitary landfills are in a known state of decomposition and where there are potential hazards, steps should be taken to provide:

   (a) Ventilation beneath and in all structures in the affected zone to prevent accumulation of explosive mixtures, odors, and possible fires.

   (b) Solutions to eliminate, decrease, or control the movement of hazardous gases from the landfill.

(6) Where gas barriers or gas control systems are installed, a reconnaissance or monitoring program should be provided to evaluate the system's effectiveness and to determine the degree of maintenance required.

(7) Provisions should be made for maintenance of completed landfills to prevent erosion, ponding of water, and sealing settlement cracks, so that moisture can not enter the landfill.

(8) The local building official, before issuing a building permit, adjacent to a landfill site, should consider the potentiality of decomposition gases moving into the area. The building should be designed to provide proper ventilation beneath and in the structure, or constructed on a foundation, either naturally impervious or so created through design and construction.

RECOMMENDED RESEARCH

Gas Dispersion and Diffusion Through Soil

Laboratory studies performed under the first-year program yielded dispersion-diffusion coefficients which had practical significance for soils within a narrow range. In order to provide for a wide range of practical application, further laboratory studies should be programmed to identify and evaluate parameters such as surface absorption, grain size distribution as identified by effective size (Dn) and uniformity (U), soil characteristics expressed as porosity (n), inlet pressure ranges, and pressure gradient characteristics. The ultimate goal would be a tool to more accurately predict gas movement through various soils.

Carbon Dioxide Contamination of Ground Water

Degradation of ground water through leachate contamination is a known fact and definitive research has resulted in ability to prepare quantitative assessment of this type of pollution. That the dispersion and diffusion of CO_2 pollutes aquifers in the absence of percolating water is not well known. One study (Reference 6) indicated that such pollution could be of major magnitude. Research, as a part of that study, was inconclusive as to all parameters of the problem. There is considerable disagreement on the part of those who have studied the problem as to the significance of CO_2 water quality degradation.

A sanitary landfill over an aquifer should be constructed under controlled conditions, and full field investigations should be carried out in order to define and evaluate all parameters of CO_2 pollution so that such pollution may be quantitatively predicted.

Demonstration Projects

New demonstration projects should be undertaken in a future research program to test the effectiveness of gas control systems and gas barriers. These demonstration projects could encompass the construction of small sanitary landfills, one in a gravel pit or a depression surrounded by coarse sand and gravel formations, and another in an area which consists predominantly of fine silt and clay materials. Dimensions of these landfills could be kept to 500 by 500 by 25 ft to reduce the cost of the project. Gas barrier and venting systems would then be implemented in these landfills. A system of gas probes would be installed at various depths around the perimeter of the fill as well as within the landfill. The results of sampling from these probes would show the degree of effectiveness of the control system installed at each fill.

APPENDIX A

LIST OF REFERENCES CITED

1. "Existing State of the Art in Solid Waste Management Systems," a report by Engineering-Science, Inc. Prepared for Aerojet-General Corporation of California, 1967.

2. "Conduction of Heat in Solids." Carslaw, H. S. and Jaeger, J. C., New York, Oxford University Press, 2nd Edition, 388, 1959.

3. "Effect of Pore Structure and Molecular Diffusion on the Mixing of Miscible Liquids Flowing in Porous Media," Raimonde, P. G., Gardner, H. F., and Petrick, C. B. A.I.Ch. E.-S.P.E. Joint Symposium on Fundamental Concepts of Miscible Fluid Displacement, Part II, Reprint 43, San Francisco, California, 1959.

4. "Diffusional and Convective Transport of Miscible Fluids in Granular Media," Bennett, E. R. and Kaufman, W. J. Sanitary Engineering Research Laboratory College of Engineering and School of Public Health, University of California, Berkeley. Serial Report No. 67-8.

5. "Gas Chromatography," Littlewood, A. B. New York Academic Press, 24, 1962.

6. "In-Situ Investigation of Movement of Gases Produced from Decomposing Refuse," Series of reports by Engineering-Science, Inc. for California Water Quality Control Board dated October 1962, October 1963, December 1964 (republished as State Water Quality Control Board Publication No. 31), November 1965, and November 1966.

7. "Fluid Mechanics," Daugherty, R. L., Sixth Edition, McGraw-Hill, 1965, 574 pp.

8. "Mass-Transfer Operations," Treybal, R. E., McGraw-Hill, 1955, 666 pp.

9. "Investigation of Leaching of a Sanitary Landfill," California State Water Pollution Control Board, Publication No. 10, 1954.

10. "Planned Refuse Disposal," County Sanitation Districts of Los Angeles County, 1955.

11. "In-Situ Investigation of Movement of Gases Produced from Decomposing Refuse," California State Water Quality Control Board, Publication No. 31, 1965.

12. "Proceedings of the 1966 Incinerator Conference," Incinerator Committee Process Industries, Div. of ASME, New York, 1966.

13. "In-Situ Investigation of Movement of Gases Produced From Decomposing Refuse," Engineering-Science, Inc., for California State Water Quality Control Board, Fourth Annual Report, November 1965.

14. "Percolation of Citrus Wastes Through Soil," Anderson, D. R., Bishop, W. D., and Ludwig, H. F. Proceedings of the 21st Industrial Waste Conference, Purdue University, La Fayette, Indiana, 1966.

15. "Waste Water Reclamation in Relations to Ground Water Pollution," California State Water Pollution Control Board, Publication No. 6, 1953.

16. "Waste Water Reclamation at Whittier Narrows," California State Water Quality Control Board, Publication No. 33, 1966.

17. "Effects of Refuse Dumps on Ground Water Quality," California State Water Pollution Control Board, Publication No. 24, 1961.

18. "Factors Controlling Utilization of Sanitary Landfill Site," Merz, R. C., and Stone, R., Final report to USPHS, National Institutes of Health, University of Southern California, 1963.

19. "Special Studies of a Sanitary Landfill," Merz, R. C., and Stone, R., Second progress report to USPHS, Dept. of Health, Education, and Welfare, University of Southern California, 1967.

20. "In-Situ Investigation of Movement of Gases Produced From Decomposing Refuse," Engineering-Science, Inc., for California State Water Quality Control Board, Third Annual Report, December 1964.

21. "In-Situ Investigation of Movement of Gases Produced From Decomposing Refuse," Engineering-Science, Inc., for California State Water Quality Control Board, Fifth and Final Annual Report, November 1966.

22. "Handbook of Chemistry and Physics," Fourty-fourth Edition, Chemical Rubber Publishing Co., 1963.

23. "Chemical Engineers' Handbook," Perry, J. H., Second Edition, McGraw-Hill, 1941, 3028 pp.

24. "Water Quality Criteria," McKee, J. E., and Wolf, H. W., Second Edition, California State Water Quality Control Board, Publication No. 3-A, 1963.

25. "Investigation of the Ground Water Quality Impairment Near Live Oak Avenue and Peck Road in Main San Gabriel Basin," California State Department of Water Resources, Report to Los Angeles Regional Water Pollution Control Board, October 1961.

26. "Los Angeles County Building Laws," 1968 Edition.

APPENDIX B

RECORD OF LANDFILL CONSTRUCTION

RESEARCH SITE NO. 1

Description of Area

The site was constructed in a sand and gravel pit. Public agencies maintain spreading grounds northeast and southwest of the site. Excess water from a dam contributes a source of water to the spreading basins. The areas surrounding the disposal site are zoned for industrial uses.

Filling Operations

In August of 1956 the State Water Quality Control Board adopted a resolution prescribing the requirements for disposal of refuse at this site. Since the site is adjacent to several spreading basins, there were restrictions placed on the type of refuse that could be placed at certain elevations. Only inert solid materials could be deposited below elevation 800 feet, USGS datum. Any Class II material (Chapter VI), including ordinary residential and commercial refuse and garbage could be deposited above elevation 800 feet, USGS datum. In December of 1958 the State Water Quality Control Board changed the restriction on elevation from elevation 800 feet to 740 feet in some locations. However, these restrictions did not affect operations at the disposal site, since the lowest elevation of the pit was approximately 840 feet, USGS datum.

Filling operations began in August of 1957. The original volume of the pit was calculated to be 787,000 cubic yards. Refuse for this site came from two sources. One public agency used the site to dispose of combined refuse collected by its Departments. A second public agency also used the site for disposal of material which included broken concrete, asphalt, tree trimmings, and other waste material from their operations.

This pit was operated as a cut and cover disposal site. Refuse was placed in nine-foot lifts and was covered each day with a one-foot layer of cover material of sand and gravel, cut from the sides and bottom of the pit.

The last refuse was placed in January 1961. Maximum depth of the fill is approximately 60 feet. At the present time, inert fill from public departments and private contractors is being placed at this site to fill depressions and to again bring the fill to final grade. The thickness of the final cover will vary from 2 ft to 18 ft.

Hydrologic Data

This disposal site is located in a ground water basin which has a surface area of 96,200 acres. Percolation of rainfall and runoff from the surrounding hills and mountains, together with imported water, are the main sources of water supply in the area. Ground water movement in the basin is in a southerly and easterly direction, converging toward narrows in the southeast corner where surplus escapes as underflow or rising water.

Geology

The disposal site is located on a major river debris cone; this cone is one of low relief which slopes radially southward with a gradient of about 50 feet per mile. The cone is restricted to the north by mountains. The site is located in a basin which totally is comprised of highly-permeable, alluvial materials, chiefly sands and gravels.

Subsidence and Gas Generation

Since the time of completion of the project there has been considerable uneven settlement of the fill, as much as 16 feet. It is believed that runoff from the unseasonably high rainfall of 1965-66 and 1966-67 was impounded by depressions, percolated into the fill and increased the rate of decomposition, subsidence and generation of gas.

RESEARCH SITE NO. 2

Description of Area

The site is located in relatively isolated inland hills, encompasses approximately 260 acres, and occupies several small canyons. Elevations at the site range from 900 feet, USGS datum, at the bottom of the canyon near the entrance to the site to approximately 1500 feet, USGS datum, at the ridge near the northerly boundary.

Initial Site Development

The site was developed from the natural state except for a small borrow excavation area in the most easterly canyon.

Filling Operations

In December 1960 the State Regional Water Quality Control Board adopted a resolution prescribing the requirements for disposal of wastes at this site. These requirements limited the types of wastes acceptable to Class II material, defined as ordinary household and commercial refuse and/or rubbish and garbage, and to Class III materials, defined as non-water soluble, nondecomposable inert materials. Subsequent to the original resolution, at the request of the public agency operating the fill in September 1965 the State Regional Water Quality Control Board altered the requirements for disposal by adopting a new resolution allowing, in addition to the Class II and Class III types of waste, the disposal of Class I material, defined as liquid and/or solid wastes with no limitation as to their nature in the majority of the area, excluding only the alluvial fill areas in the lower portions of the canyons.

Filling operations by a public agency began in early 1961 in the westerly branch of the main canyon. Rubbish was placed in layers approximately three-foot in depth and covered with at least nine inches of earth. The first area of fill has now been completed and filling is now proceeding in the canyon near the southwesterly corner of the site.

Post Site Development

Because filling operations are still in progress, no post site development of the completed areas has occurred. These areas have been surveyed and bench marks established to observe settlement of the fill.

Geology

The site is immediately underlain by middle Miocene deposits of the Topanga Formation, with outcrops of the late Miocene Modelo Formation at the northeast margin of the site, and Recent alluvium appearing along the southeast margin.

The Topanga Formation includes predominantly medium-to-coarse-grained sandstone and conglomerate with lesser amounts of interbedded shales. Interfingering, lensing and lateral gradation of beds within this formation are common. The sandstone is generally well cemented with low porosity and low permeability. However, there are local sandstone and conglomerate beds that are poorly cemented and can permit the storage and transmission of ground water.

The Modelo Formation consists predominantly of brittle, thin-bedded, highly fractured shales and mudstone, production of water from which is very limited.

Hydrologic Data

Although the sediments of both the Topanga and Modelo Formations are highly folded and fractured, faulting is almost absent. The steep dips (30-40 degree) of the beds restricted horizontal movements of liquids. Because of the relatively impervious nature of these materials, it is considered that wastes deposited on the site, except in the small alluvial areas, are essentially hydraulically isolated from the ground waters of adjacent canyons where alluvial deposits from water-bearing strata exist. One water well at the site penetrates conglomerate and sandstone beds of very low permeability within the Topanga Formation; pump test data indicate permeability values of from 10 to 20 gallons per day per square foot. Ground water levels in this well have no relation to water levels in wells located in the alluvium.

The drainage area tributary to the disposal facility is about 95 acres. The main streams draining the area flow in a southeasterly direction and ultimately converge with creeks which continue to the ocean some eleven miles south of the site. A minor stream draining the northwest corner of the site flows west. There are no known direct diversions or uses made of the waters of the main creek, in the vicinity of the disposal site, but waters draining from this area through the creek system form an important source of recharge for the underlying ground water basins.

Water is drawn from wells along these main creeks for domestic and agricultural uses. The quality of these ground waters is unsatisfactory by the United States Public Health Service Drinking Water Standards and is Class 3 for irrigation purposes. There are no water wells within one-half mile of the disposal site.

Project Investigation to Date

A study of gas movement was started by the public agency operating the fill and has been incorporated and continued as part of this project, designated as Site No. 2A. Settlement studies are being conducted on a completed portion of the site, designated Site No. 2B.

RESEARCH SITE NO. 3

Description of Area

The site is located in the southern area of Los Angeles County in unincorporated county territory. This site is one of several in a low lying, poorly drained, slough area which has previously been unsuitable for development. Drainage for the area is accomplished by a storm drain which discharges to a main drainage channel. Development in the vicinity of the site includes residential to the south and west, and industrial to the north. A soccer field has been constructed on the southern portion of the rubbish fill and a truck parking area on the northern portion.

Initial Site Development

The site was crossed by a natural drainage channel which meandered generally from west to east. The original low elevation was approximately 10 feet, USGS, and high elevation approximately 31 feet, USGS. Prior to development it appeared that water ponded on the site after storms, possibly to a depth of 10 feet or more, due to the high elevation of the outlet culvert.

Filling Operations

An Industrial Waste Disposal Permit was issued on 1 September 1959 for the operation of a Class II rubbish disposal facility on the site. Operations were carried out by first excavating to elevation +0.5 feet USGS, Sea Level Datum of 1929. Rubbish was backfilled in three-foot lifts. The area for filling operations was 22.32 acres, giving an initial volume of 1,078,340 cubic yards. Soil was mixed with rubbish in the approximate ratio of 1 to 4 and water was used to aid compaction. Final rubbish elevations are generally two feet below the finish elevation shown on the construction plan. No rubbish was placed in the southern, western, or northern 150 feet of the site. The eastern limit of rubbish is not known but it is assumed to be the easterly property line along the freeway frontage road right-of-way. No rubbish was placed in the freeway right-of-way, the storm drain channel or water main easements. Filling operations progressed generally from west to east. The fill was completed and operations closed down in May 1962.

Post Site Development

Plans were made to develop the portion of the landfill south of the storm drain channel. These plans included a soccer field and shopping center. The soccer field and its adjoining buildings were constructed in 1966. Construction is expected to begin on the shopping center complex within the project period of this study. In addition, a parking area adjacent to the soccer field has been constructed.

Four, 15-foot by 27-foot buildings constructed in conjunction with the soccer field are located over rubbish fill. Each building is of similar construction having a floating concrete foundation laid over a system of 14-inch by 14-inch gravel-filled trenches. Each trench is vented to the side of the building. To this date no settlement or gas problems have been recorded. Soil test reports for both phases of development were made prior to construction.

The northern portion of the site is occupied by a trucking facility. Several buildings, included in the development, are constructed in the northern 150 feet on solid fill. The open area from the buildings southerly to the storm drain channel is paved and used for truck parking and is part of the rubbish fill.

Hydrologic Data

The hydrologic and geologic conditions of this site are identical with those for Site No. 6.

The site is situated in the central part of the West Coast Ground Water Basin which supplies more than 65,000 acre-feet of water annually for domestic, municipal, industrial, and agricultural purposes. Under the site are four water-bearing sand and gravel layers. The uppermost is known as the semiperched zone. Other water-bearing strata beneath this zone are the "200-foot sand," the "400-foot gravel," and the Silverado.

Generally, the deeper zones produce better quantity water than the upper zones. Ground water from the semiperched zone has been found to be suitable to marginal for domestic and irrigation purposes. At the time of construction, there were seven wells producing from the semiperched zone and the "200-foot sand" for stock and domestic purposes within a two mile radius of the site.

The recorded high ground water elevation of the semiperched zone in the vicinity of this site was 8.0 feet above sea level. Although similar high water level may reoccur, the Department of Water Resources felt that sea level could be considered a reasonable maximum ground water elevation of the dump site and adjacent area were properly drained. From this information, the lower limit for placing of rubbish was set at 0.5 feet.

Geology

The site occupies a topographic low or slough area which is underlain by a thin veneer of recent alluvial deposits consisting of clay, silt and fine sand. The thickness of these deposits is not readily determined because of their similarity to the underlying and more extensive upper pleistocene sediments. These upper pleistocene deposits are divided into an upper portion of fine-grained sediments containing the semiperched water-bearing zone and lenses of impermeable silt and clay, and a lower portion of coarser materials which form the "200-foot sand."

In the vicinity of the site, the semiperched zone is separated from the "200-foot sand" by a considerable thickness of sandy silt and clay lenses which restrict downward percolation. In an area several miles to the southeast of the site, continuity exists between the semiperched zone and the "200-foot sand" and lateral migration of ground water may occur in that direction.

Gas Investigations to Date

No previous studies relative to gas production and movement for this site have been made. The operators of this disposal facility were conscientious and constructed the fill in a proper manner, which probably accounts for the lack of both gas and settlement problems at the site.

RESEARCH SITE NO. 4

Description of Area

The site was constructed in a small canyon in the inland foothills of Los Angeles County. Elevation of the bottom of the canyon at the foot of the fill is about 1,250 feet. The elevation at the divide at the upper end of the fill is 1,500 feet. These two points are about 2,000 feet apart horizontally. The ridge to the east of the dump rose to more than 1,500 feet in elevation before it was cut off for cover material in the landfill. This ridge is presently the site of a trailer park.

Filling Operations

Filling of the site began in September 1955. Initially, a fan shaped fill was made with the apex at the entrance in the saddle in the ridge on the east side of the canyon, and spreading across the canyon to the north. Thousands of citrus, walnut, olive and avocado trees were deposited in the fill during the first few months of operation, in addition to assorted rubbish. The fill sloped to the west and a drainage channel was maintained on original ground along the westerly edge of the fill area.

In 1957, approximately 70,000 gallons of spent sulfuric acid (Ferrous sulfate and sulfuric acid, about 5 percent) were dumped into the site at two locations. The areas used in this experiment are now covered with about 70 feet of fill. The acid was apparently neutralized before it reached any rubbish.

A total of about 1,500,000 cubic yards of material was deposited in the fill. The surface of the fill at the time of completion was in three levels, at elevations 1,440 feet, 1,475 feet, and 1,525 feet.

From November 1959 until completion in June 1961, the site was operated by a public agency under a lease from the owner. The fill was completed in June 1961 and covered with at least 2 feet of clean earth. The operator was anxious to start construction of a trailer park and did not attempt to fill every possible space with rubbish. In some places, it is believed that the dirt cover is 10 to 12 feet thick.

Post Site Development

A trailer park was constructed on the cut area adjacent to the site immediately after completion of the fill. The westerly portion of the park is believed to be on rubbish fill and has been affected by settlement and gas problems. A sewage collecting system and septic tank was installed to serve the trailers with a leaching field in the rubbish fill. The area of the leaching field shows greater settlement than the rest of the fill. This settlement has caused cracks to appear in several trailer pads and at various places in the road.

Hydrology

There are no water-bearing formations in the landfill area. A maximum of 90 cubic feet per second of surface runoff can be expected at the lower end of the site.

Geology

The southern portion of the site overlies the Modelo formation which is a series of sandstone and shale beds dipping from 25 to 40 degrees northerly. This formation is considered nonwater-bearing. The northern portion overlies sandstone and shale beds of the Pico formation which is older than the Modelo and which dips to the north at from 25 to 35 degrees. This formation is also nonwater-bearing. Both are of marine origin.

Subsidence and Gas Generation

Gas is being generated in the rubbish fill to the extent that a collecting system has been installed to collect and burn the gas adjacent to the trailer park.

Subsidence has occurred over most of the dump area creating problems in maintaining pavement on the access road to the trailer park and on several trailer pads.

The area in which subsidence and gas production appear to be maximum is the area in and around the leaching field for the sewage disposal system.

RESEARCH SITE NO. 5

Description of Area

The site is located in coastal hills. A private company mined diatomaceous earth from the site until about 1950. A public agency acquired the site in 1956.

Initial Site Development

Prior to acquisition by a public agency, the site was a pit of about 6,000,000 cubic yards, containing numerous loose deposits of excavated material (mine tailings). Depths varied up to about 200 feet. The area of the pit was about 55 acres.

Filling Operations

A permit for Class II dump operation was issued to the public agency owning the site on 17 April 1957. Filling proceeded at a rate of about 20,000 cubic yards per month until this area was completed in 1966. The total weight of material deposited in this area was 4,107,227 tons, or approximately 6,000,000 cubic yards.

Post Site Development

Another public agency is currently developing the site as a botanical garden.

Hydrologic Data

There is no evidence of ground water underlying any portion of the site.

Geology

The site is underlain by alternating deposits of 2 to 6 feet thick, of Valmonte diatomite and diatomaceous mudstone with some included limestone concretions and lenses of Monterey shale series, having, in general, a northeast dip. This series of relatively impermeable siliceous deposits underlies and dips well beneath the very permeable lower Pleistocene water-producing sands which outcrop along the northeast flank of the hills. The diatomite phases are composed of siliceous, very fine grained, gritty, clay-like material with a porous texture.

Gas Investigations to Date

Gas problems developed along one side of the fill in 1966. The public agency owning the site made an investigation and took remedial action as described in Chapter V of this report.

RESEARCH SITE NO. 6

Description of Area

The site comprises about 37 acres located in the southern area of Los Angeles County. The site is one of several in a low lying, poorly drained, slough area on which storm waters had been impounded during rainy seasons for many years. Present development of the surrounding area includes recreational and commercial developments on completed refuse disposal sites adjacent on the south and the east, and industrial to the north.

Initial Site Development

Plans for the construction of the site show the original topography and the proposed finish grades. No excavation was made within a street easement and/or utility easement which cross the property, and filling in those areas has been limited to inert solid material. The remainder of the site was excavated to an elevation of about 20 feet below sea level and filled with inert solid material to elevation 0.5 feet above sea level before rubbish was deposited.

Filling Operations

Filling operations are currently in progress and are being carried on in accordance with a County Industrial Waste Disposal Permit issued on 6 October 1964, for the operation of a Class II disposal site. Rubbish is mixed with dirt at a ratio of one part of dirt to four parts of rubbish and compacted in layers up to 8 feet deep, then covered with at least one foot of dirt. The site is operated 24 hours a day.

Drainage of the northerly portion of the site has not yet been provided but plans have been approved for a holding basin at the northwest corner of the site with provisions for pumping storm water from the basin into a storm drain.

Post Site Development

Several proposals for use of the site when completed are being considered by the operators and owner of the site, but no definite plans have as yet been approved.

Hydrologic Data

A report by the State Department of Water Resources to the Regional Water Quality Control Board dated 4 December 1956, indicated that the site is situated in the central part of the West Coast Ground Water Basin which supplies more than 65,000 acre feet of water annually for domestic, municipal, industrial and agricultural purposes. Under the site are four water-bearing sand and gravel layers. The uppermost is known as the semiperched zone. Other water-bearing strata are the Gage aquifer of "200-foot sand," the "400-foot gravel" and the Silverado zone.

Generally, the deeper zones produce better quality water than the upper zones. Water from the semiperched zone has been found suitable to marginal for domestic and irrigation purposes.

The recorded high ground water elevation of the semiperched zone in the vicinity of the site is 8.0 feet above sea level. Although similar high water levels may reoccur, sea level may be considered a reasonable maximum ground water elevation if the dumpsite and adjacent areas are adequately drained.

Geology

A large portion of the site occupies a topographic low or slough area which is underlain by a thin veneer of Recent alluvial deposits consisting essentially of clay, silt and fine sand. Thickness of these sediments is not ascertainable because of their lithologic similarity to the underlying more extensive upper Pleistocene sediments. Upper Pleistocene deposits are divided lithologically into an upper portion of essentially fine-grained sediments containing a semiperched zone and lenses of impermeable silt and clay, and a lower portion of coarser materials which form an aquifer designated the "200-foot sand." At the site, the elevation of the top of this aquifer is approximately 100 feet below sea level. Well logs indicate that the semiperched zone is locally separated from the "200-foot sand" by a considerable thickness of sandy silt and clay lenses which restrict downward percolation, but hydraulic continuity does exist in an area several miles to the southeast. Lateral migration from the area underlying the site to this area of hydraulic continuity is possible but its rate and quantity are not known. Because of the discontinuous nature of the sediments, it is believed that any lateral movement would be at a slow rate and of small magnitude. Throughout the greater part of West Coast Basin the "200-foot sand" exists as a distinct aquifer; however, in the area that lies south and west of the site, it is merged with the "400-foot gravel," a lower Pleistocene productive aquifer. Within this area, the "400-foot gravel" overlies and is in hydraulic continuity with the extensive and very productive Silverado water-bearing zone.

Gas Studies to Date

No studies on the production and movement of gases generated by the sanitary landfills in the area have been made.

RESEARCH SITE NO. 7

Description of Area

The site is located in a large canyon in hills situated in the central part of the study area. The fill is being constructed by a public agency as a park reclamation project and is entirely surrounded by park grounds.

Initial Site Development

The original topography of the canyon was obtained by the public agency constructing the fill. Each year new topography is taken and maps prepared for use in calculating the remaining volume of the canyon.

Filling Operations

In 1957, the State Water Quality Control Board issued a permit to the public agency to operate a Class II disposal site at the canyon site.

The requirements limited the fill material to household and commercial combustible and noncombustible refuse and garbage.

Filling operations began in the summer of 1957, and are continuing at the present time. The original volume of the canyon was estimated to be approximately 9,500,000 cubic yards. The fill for the site comes from two sources. Currently, the sanitation department of the public agency collects and disposes of approximately 447,000 tons per year of combined refuse at the site. The other departments of the public agency dispose of approximately 150,000 tons of refuse per year at the site. Most of this is solid, inert material.

The sanitary landfill is operated as a cut and cover disposal site. The refuse is placed in the fill in nine-foot lifts and covered each day with a one-foot layer of cover material. The cover material is cut from the sides of the canyon and is mostly sandstone and decomposed granite.

Post Site Development

In the study area there is a lack of usable recreation space. The canyon site is one of many steep canyons that cannot be used for recreation purposes. However, when the east canyon is filled, there will be a flat area of approximately forty acres that will be suitable for many recreational purposes.

Hydrologic Data

The surface runoff from the canyon is tributary to the Los Angeles River. Surface runoff, except rain falling naturally on the fill, is prevented from passing over or percolating through the refuse. There are no known wells in the immediate vicinity and no evidence of ground water in the area.

Geology

The Hollycrest formation of middle Miocene age underlies the area in the vicinity of the site. This formation consists of an upper shale, clay and arkose member underlain by a boulder conglomerate member.

Subsidence and Gas Generation

There have been no known gas problems at the site. In certain areas of the fill, subsidence and lateral movement is determined annually. This data is presented in Chapter III (Table III-8).

RESEARCH SITE NO. 8

Description of Area

The site is one of the many sand and gravel pits located along an alluvial cone formed by two rivers. Sand and gravel quarrying operations were completed in 1949. A public agency maintains spreading grounds adjacent to and southwest of the site. These spreading grounds were actually a portion of the original pit. Drainage from a wash and a dam contribute water to the spreading basin. A residential development, constructed in 1947, is located adjacent to the northerly side of this site. A salvage yard and a truck maintenance yard are located on the easterly portion of the site.

Initial Site Development

The original pit, mined between 1937 and 1949, extended partially into the area of the spreading basin on the south and attained a depth at this point of approximately 70 feet and an elevation of 275 feet. From this point the bottom of the pit sloped, on a more or less straight grade, to a point adjacent to the residential development at the extreme northeasterly end of the pit (a depth of approximately 25 feet and an elevation of 325 feet). The edge of this fill is approximately 10 feet from the property line of the residential development. During the fill operation, a public agency developed a spreading basin and a levee was constructed of inert fill material to physically separate the basin from the proposed refuse fill site.

The actual surface area available for filling amounted to approximately 40 acres.

Filling Operations

In 1954, the Los Angeles Regional Water Quality Control Board adopted a resolution to permit a private operator to operate this refuse disposal site. The resolution limited the depth of fill for the area to above elevation 325 feet for the depositing of refuse. The area below elevation 325 feet was reserved for only solid inert fill material.

An estimate was made by a consultant which reported an available capacity of 800,000 cubic yards above elevation 325 feet and 1,600,000 cubic yards below that elevation. Unofficial reports have suggested that decomposable refuse was placed below this elevation; subsequent test holes have confirmed these reports. Based on the evidence of these test holes, it can be stated that the operator failed to comply with the requirements of the State Regional Water Quality Control Board.

A resulution, adopted by the Board in 1954, described the proposed operation as a cut and cover dump. The actual method of placement of refuse used is not known, but it is likely that very little solid earth was mixed with the refuse. The thickness of the final earth covered over the fill was not specified by the permit. However, an approximate thickness of four feet is known to have been placed over the northeasterly half of the fill to support the trailer park.

Post Site Development

A trailer park was constructed on the northeasterly portion of the fill area, late in 1962. The original facilities for the park consisted of 96 concrete trailer pads with asphalt connecting roads, a recreation building equipped with a fireplace, and a swimming pool. Plans were not available showing construction details for these facilities.

Early in 1963, noticeable subsidence occurred, requiring repairs on all of the facilities and resulting in the abandonment of the swimming pool. Another area of obvious settlement occurred at a block wall adjoining a salvage and truck maintenance yard on the east side of the site. Settlement in other portions of the park exceeded 5 feet. No survey benches were established in the park to measure this settlement and subsidence.

The uneven settlement of the portion of the site outside the trailer park area has caused the ground surface to become uneven, preventing surface water to drain away. During 1967, the trailer park operation at this site was discontinued because the owner was unable to maintain the park in a safe condition. Differential settlement caused broken gas and utility lines and excessive maintenance costs.

Hydrologic Data

The site is located upon a major ground water basin, which is an important source for storage and distribution to a large residential and industrial community. The ground water is replenished by deep percolation of runoff from two rivers. Other contributing sources consist of imported waters and reclaimed wastes.

There are many supply and test wells in the area, providing ground water quality information and historical ground water elevations. The period of time covered by these records extends from approximately 1950 to the present time. The general ground water gradient indicates a movement in the southwesterly direction. The maximum historical ground water elevation near the site, in 1944, was recorded at elevation 320 feet.

The State Department of Water Resources presented, for this area, a report in 1961 for the Regional Water Quality Control Board No. 4, entitled "Ground Water Quality Impairment." The report provides extensive detailed data of existing wells including data from three test wells, one of which was located in the northeast portion of the refuse fill. Data from these test wells include water quality information and logs of the materials encountered. The test wells were maintained only during the course of the study.

The report discusses potential sources of impairment caused by the distribution of carbon dioxide gas through the alluvium. It was concluded that the majority of this was being contributed by the various landfill sites in the area. It was also found that water quality impairment occurred only in wells which were known to be perforated at depths less than 150 feet below the ground surface.

Geology

The site is located on a broad alluvial cone developed by the deposit of errosional debris carried by storm runoff from nearby mountains. This cone consists, generally, of sand and gravel which extends to great depths into the water-bearing aquifers.

RESEARCH SITE NO. 9

Description of Area

This site is located in the County of Orange and was constructed by a public agency in an abandoned gravel pit, leased from a private company. The site is situated adjacent to a main natural drainage course. The area south of the site is zoned for residential use. Gravel and sand mining operations are currently in progress in areas adjacent to the site.

Filling Operations

The total area of the site is 16 acres and had a total refuse capacity of approximately 1,400,000 cubic yards. Filling of the site began in March 1962, and was completed in February 1966. The site was approved by the state agencies for disposal of Class II material. Final cover consisted of three feet of fine silty soil.

Post Site Development

No development of the completed site has started, but master planning for the area proposes regional park development.

Hydrologic Data

The site is located within a major ground water basin and within a partly restricted water conservation percolation zone. The general ground water gradient is to the south, with existing ground water elevations for the area being approximately 10 feet.

Geology

The site is located in a major drainage basin consisting of alluvium-filled deposits of silts, sands and gravels.

Subsidence and Gas Investigations to Date

The public agency that constructed the fill has initiated an annual survey program to check on settlement at the site and have made periodic investigations and measurements of gases being generated at the site.

RESEARCH SITE NO. 10

Description of Area

This site is privately owned and is located in the San Francisco Bay area. It is one of many in the area reclaiming tidal lands by the construction of sanitary landfills. It was constructed by the erection of solid fill levees around low-lying tidal lands of the bay and subsequent pumping of water from the area enclosed by the levees. The levees prevent the inundation of the site by seawater and serve as the outside perimeter of the fill site.

Filling Operations

The filling of this site has been continuous since 1945 using a cell type fill and cover method of construction for residential, commercial and industrial solid wastes. Depths of fill vary from 25 to 30 feet.

Subsidence to Date

Periodic elevations are taken on the completed portions of the fill to measure settlement.

APPENDIX C

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 1 Temperature: 80° - 90° Weather: Clear-Hot

Date Sample Taken: July 26, 1967

Date Sample Analyzed: July 31, Aug. 4 & 7, 1967

Probe No.	CO_2	O_2	N_2	CH_4
1	6.2	15.6	78.2	0.1
2	17.8	4.0	78.2	Trace
3	36.3	0.9	33.2	29.6
7	36.7	2.8	24.4	35.0
8	43.0	0.5	7.1	46.5
9	38.2	0.8	25.0	34.0
13	43.0	0.5	7.2	45.7
14	42.3	0.5	11.3	42.5
15	45.3	0.5	6.5	44.8
16	38.6	0.7	25.2	32.6
17	26.7	4.3	44.0	20.9
18	20.7	0.7	63.5	11.8
19	43.7	0.4	3.4	47.4
20	Flooded			
21	10.7	13.2	69.8	2.0
22	41.2	1.0	16.2	37.6
23	43.4	0.5	5.5	45.7
24	39.7	2.1	25.8	27.6
25	3.3	19.4	72.4	Trace
26	7.5	15.3	75.5	NIL
27	43.7	0.8	14.9	40.2
28	7.0	17.2	73.5	0.9
29	42.3	0.4	10.2	43.8
30	4.9	18.3	75.8	Trace
31	29.1	1.0	41.0	25.3
32	38.6	0.3	19.2	38.7
33	39.2	0.3	17.5	39.0
37	42.3	0.4	2.3	49.3
38	4.1	18.0	74.0	Trace
45	9.7	13.9	77.0	Trace
52	26.4	3.3	61.8	8.6
55	34.8	1.0	44.3	20.5
56	40.4	0.6	19.0	40.2
57	42.3	0.5	11.4	43.8
58	44.9	0.3	1.2	49.8
59	40.7	0.7	20.4	37.5
60	34.5	0.9	42.5	20.7
61	36.0	0.8	31.7	29.4
62	43.0	0.3	4.7	47.8

Probe No.	CO_2	O_2	N_2	CH_4
64	47.6	0.3	1.3	49.8
65	47.2	0.3	1.3	50.5
66	46.2	0.3	1.3	51.4
67	43.8	1.4	5.7	48.4
63	43.1	0.8	11.6	44.3
4	43.5	0.4	8.0	46.5
5	39.7	2.2	11.9	43.8
6	42.0	1.8	9.3	45.3
10	46.2	0.3	1.7	49.3
11	45.3	0.5	2.2	48.8
12	28.2	8.9	33.8	28.7
34	46.2	0.1	1.1	51.1
35	45.3	0.5	2.6	49.8
36	46.2	0.6	2.7	49.8
39	10.3	12.3	73.5	0.1
40	13.3	10.5	71.3	1.0
41	5.2	17.5	71.3	1.4
42	3.0	19.1	73.5	Trace
43	26.7	3.9	53.5	12.8
44	14.4	12.0	72.6	Trace
51	31.1	1.3	53.5	14.4
50	32.6	1.0	50.2	16.0
49	9.2	14.2	75.8	Trace
48	25.8	1.3	69.5	3.7
47	30.0	1.4	56.2	12.2
46	29.4	4.2	51.8	14.2
53	25.3	2.1	67.7	4.5
54	33.3	1.6	39.8	23.7

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 1 **Temperature:** 75° - 85° **Weather:** Clear & Warm

Date Sample Taken: Oct. 24, 1967

Date Sample Analyzed: Oct. 30, 1967

Probe No.	CO_2	O_2	N_2	CH_4
4	35.5	0.5	17.7	45.8
5	38.6	1.4	8.1	51.5
6	40.5	0.5	6.4	54.0
10	40.5	0.5	6.6	52.0
11	41.4	0.6	2.8	53.0
12	42.5	0.8	5.5	54.0
34	41.6	0.2	4.1	55.0
36	41.2	0.3	4.1	54.0
35	42.3	0.5	2.3	55.0
1	6.9	15.4	78.0	0.1
2	17.1	2.9	80.0	0.3
3	33.0	0.9	35.5	32.3
7	38.4	0.5	17.0	43.1
8	39.4	0.5	10.7	46.6
9	42.3	0.4	3.8	52.0
13	42.3	0.2	3.6	51.1
14	35.3	1.6	21.2	39.4
15	40.5	0.2	3.4	52.0
16	34.2	0.9	37.3	31.9
17	26.6	1.3	59.0	16.6
18	17.9	1.3	68.8	9.2
19	44.2	0.5	2.9	52.2
23	44.5	0.2	1.3	54.9
24	39.3	1.1	16.0	47.7
25	0.7	21.9	77.2	Trace
26	1.1	21.9	75.0	0.0
27	38.5	0.6	16.0	43.6
28	8.3	15.6	72.6	2.8
29	40.4	0.7	6.5	49.5
30	2.9	24.0	74.0	Trace
31	28.5	1.2	45.0	24.2
32	37.9	0.6	15.4	44.0
33	36.3	0.8	24.0	37.6
38	3.3	18.5	79.0	Trace
39	8.7	12.7	75.0	0.8
40	16.2	7.1	73.0	Trace
41	11.1	11.3	74.0	Trace
42	2.9	20.9	77.0	0.0
45	21.9	4.4	71.0	2.3
46	24.2	4.1	65.0	9.3
47	23.5	1.8	66.0	7.9

Probe No.	CO_2	O_2	N_2	CH_4
48	23.5	1.3	68.0	6.2
49	9.5	14.7	79.0	Trace
52	22.8	2.9	72.0	4.1
53	15.7	6.9	78.0	0.2
54	30.2	2.9	45.0	22.0
55	32.9	0.9	45.5	20.4
56	36.6	0.8	31.9	31.0
57	38.8	1.6	18.5	41.0
58	47.6	0.3	1.6	51.2
59	42.4	0.7	15.5	44.0
60	37.3	0.9	26.7	35.0
61	32.5	5.5	32.5	33.0
62	35.8	7.0	19.0	42.5
63	44.0	0.3	9.1	48.5
64	47.6	0.4	1.8	53.0
65	48.4	0.2	0.8	53.0
66	47.6	0.2	0.6	54.0
67	47.6	0.2	0.7	54.0

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 2A Temperature: -- Weather: Clear & Hot

Date Sample Taken: May 15, 1967

Date Sample Analyzed: May 17 & 18, 1967

Probe No.	CO_2	O_2		N_2	CH_4
1	44.5	1.4		50.6	Trace
2	51.8	2.3		45.5	Trace
3			Plugged		
4			Plugged		
5	32.5	7.7		62.3	NIL
6	29.8	3.2		69.5	NIL
7	31.2	1.5		68.3	NIL
8	24.0	2.2		70.2	NIL
9	24.7	1.6		71.5	NIL
10	26.6	1.7		72.3	NIL
11	26.7	1.5		69.5	NIL
12	24.7	3.0		70.0	NIL
13	15.5	10.2		74.0	NIL
14	9.0	16.8		72.4	NIL
15	25.4	3.4		69.5	
16	36.7	1.9		59.0	NIL
17	13.1	14.2		69.0	NIL
18	47.0	2.2		48.5	NIL
19	29.8	6.2		61.6	NIL

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 2A Temperature: 90° Weather: Clear & Bright

Date Sample Taken: July 7, 1967

Date Sample Analyzed: July 13, 1967

Probe No.	CO_2	O_2	N_2	CH_4
1	68.1	1.0	29.5	0.3
2	60.2	2.4	34.0	0.3
5	53.1	1.7	43.2	Trace
6	37.8	2.5	57.0	Trace
8	35.3	1.5	60.5	Trace
9	36.1	1.5	59.4	Trace
10	29.6	1.8	66.4	Trace
11	31.4	1.7	63.5	Trace
12	30.8	2.2	64.0	Trace
13	30.4	1.8	65.7	Trace
14	42.3	2.9	53.0	Trace
15	31.0	2.3	64.0	Trace

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 2A   Temperature: 85° F   Weather: Clear - Warm

Date Sample Taken: September 12, 1967

Date Sample Analyzed: September 18, 1967

Probe No.	CO_2	O_2	N_2	CH_4
1	57.0	2.1	41.5	0.7
2	81.0	0.7	18.2	2.0
3	68.0	2.3	31.0	Trace
4	24.0	11.8	62.5	Trace
5	65.0	3.6	32.5	0.0
6	48.4	3.1	48.5	0.4
7	56.6	1.2	42.0	0.3
8	59.3	1.1	39.0	0.6
10	55.8	1.5	45.0	0.3
11	37.9	2.1	56.5	Trace
12	43.6	2.1	55.0	Trace
13	40.6	1.5	58.0	Trace
14	52.8	2.0	46.6	Trace
15	33.5	5.1	60.0	0.0
16	58.3	1.1	41.7	0.0
17	46.2	3.7	49.5	0.0
18	65.3	1.4	31.4	0.0
19	60.5	1.5	37.0	Trace

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 3 Temperature: 80° F Weather: Clear

Date Sample Taken: July 14 & 17, 1967

Date Sample Analyzed: July 20 & 21, 1967

Probe No.	CO_2	O_2	N_2	CH_4
1	19.8	1.2	75.3	2.8
2	4.0	18.9	75.3	NIL
3	3.9	18.9	74.8	NIL
4	3.1	19.6	75.5	Trace
5	2.5	19.8	74.0	Trace
6	2.7	19.8	74.8	NIL
7	2.4	20.0	74.0	NIL
8	40.0	0.2	21.9	34.3
9	38.2	0.3	18.0	39.0
10	24.2	1.8	63.5	7.3
11	27.5	1.1	54.6	14.0
12	26.4	1.2	60.0	7.1
13	23.5	1.4	70.4	1.3
14	4.8	17.9	73.3	NIL
15	19.2	3.3	73.3	0.6
16	4.8	17.9	72.8	NIL
17	5.0	18.1	72.8	NIL
18	7.7	15.6	72.8	NIL
19	10.2	14.7	71.1	NIL
20	19.8	3.8	71.6	0.8
21	22.7	4.3	65.2	6.0
23	5.8	16.0	73.3	NIL
24	0.3	20.8	78.2	NIL
25	1.5	20.7	76.9	NIL
26	2.5	20.8	76.9	NIL
27	33.1	1.0	43.0	23.4
28	27.5	1.2	46.9	23.0
29	19.5	3.4	74.8	0.3
30	9.4	15.2	73.3	Trace
31	8.8	14.5	74.8	Trace
32	16.7	7.5	73.3	0.4
33	23.2	1.9	72.5	0.7
34	33.8	0.8	31.5	31.7
35	31.8	0.9	47.5	17.0

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 3 Temperature: 75° - 80° F Weather: Clear-Warm

Date Sample Taken: January 24, 1968

Date Sample Analyzed: January 31, 1968 & February 1, 1968

Probe No.	CO_2	O_2	N_2	CH_4
1	22.3	1.3	68.5	6.9
2	3.4	18.2	77.0	Trace
5	2.5	18.5	77.8	NIL
8	39.7	0.3	8.2	46.5
9	36.1	0.6	20.7	39.0
10	28.2	1.0	52.5	16.5
11	30.5	0.8	43.9	21.8
12	28.8	1.1	54.1	14.1
13	26.0	1.2	65.0	7.5
14	5.4	15.6	78.5	Trace
15	14.8	6.3	79.9	NIL
16	2.7	18.2	79.2	NIL
18	2.0	19.6	77.4	NIL
19	4.6	18.3	77.0	NIL
20	12.2	11.6	76.6	NIL
21	23.5	1.4	58.1	16.7
22	26.1	1.2	55.5	16.1
23	0.5	20.5	76.3	Trace
23	0.1	20.9	76.0	NIL
24	0.15	20.8	76.0	NIL
24	0.6	20.5	75.7	NIL
25	0.15	20.5	75.9	NIL
26	2.5	18.6	75.7	NIL
30	1.3	19.9	75.7	0.5
30	14.0	8.0	72.4	3.8
28	9.6	14.3	62.8	9.1
27	26.8	5.6	33.5	29.8

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 4 Temperature: 85° Weather: Clear & Warm - Smog

Date Sample Taken: July 6, 1967

Date Sample Analyzed: July 11, 1967

Probe No.	CO_2	O_2	N_2	CH_4
205	3.4	19.6	76.8	NIL
202	23.6	4.5	73.3	NIL
2	33.2	2.0	53.3	14.0
3	6.6	17.5	74.5	0.3
302	10.0	14.5	75.4	NIL
304	31.0	1.6	60.0	8.3
4	4.3	18.9	75.0	NIL
402	45.6	0.3	6.4	46.5
406	6.9	16.0	75.0	Trace
5	13.8	10.6	73.8	NIL
503	37.5	0.7	40.5	21.5
504	46.7	0.2	3.0	48.2
605	31.1	0.9	46.0	21.3
603	45.3	0.2	1.2	50.5
602	5.5	17.8	73.3	Trace
6	4.5	18.6	73.8	Trace
705	8.8	14.8	72.9	NIL
703	22.5	3.4	72.4	NIL
702	42.6	0.7	28.5	27.2
7	4.2	18.6	73.3	0.3
803	38.6	0.5	20.0	39.3
801	24.7	0.8	40.2	25.1
8	19.7	6.2	66.8	7.2
902	5.0	17.3	74.5	0.3
901	32.7	4.7	31.9	28.6
9	43.3	0.2	0.6	52.3
1002	12.5	10.3	74.5	0.7
1001 N	45.6	0.3	0.8	49.8
1001 S	Trace	20.2	73.8	Trace
10	22.7	6.4	56.7	11.7
1101	30.9	2.3	46.9	17.5
1102	27.3	7.9	33.0	29.3
1 L	21.6	9.0	45.5	20.7
2 L	3.7	18.1	74.5	Trace
3 L	36.7	2.0	13.0	45.5
4 L	30.0	0.4	22.5	43.0
FB 1	44.2	0.9	7.7	43.0
FB 2	34.2	4.8	20.0	37.5
FB 3	32.6	4.2	32.5	27.4
FB 4	26.7	4.3	51.0	15.2
FB 5	36.8	4.0	16.8	40.2

Probe No.	CO_2	O_2	N_2	CH_4
FB 6	18.8	8.0	59.5	12.4
FB 7	27.2	6.5	46.0	19.7
FB 8	28.5	6.8	37.5	26.0
FB 9	26.3	6.2	48.5	17.0
FB 10	3.6	18.6	75.5	0.2
FB 11	4.1	17.2	77.0	Trace
FB 12	41.9	3.1	15.0	41.5
FB 13	46.0	0.2	1.6	50.5

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 4 Temperature 65°F Weather: Warm - Overcast

Date Sample Taken: February 21, 1968

Date Sample Analyzed: February 28, 1968

Probe No.	CO_2	O_2	N_2	CH_4
205	4.8	16.3	74.8	NIL
202	30.4	1.2	53.5	12.5
2	34.8	0.8	41.0	19.8
3	5.9	17.0	73.4	Trace
302	10.3	11.9	74.8	Trace
304	31.7	1.8	50.7	14.0
4	4.7	17.6	73.4	Trace
402	44.5	1.3	6.8	41.7
406	6.9	15.3	72.9	0.1
5	27.4	1.2	57.4	7.6
503	43.8	1.0	6.8	42.3
504	44.5	0.3	2.3	45.9
6	5.0	17.5	72.9	0.1
602	15.9	4.4	74.8	0.1
603	45.2	0.3	1.8	46.8
605	36.3	0.6	10.8	46.3
7	3.9	18.3	72.9	0.2
702	31.3	0.9	36.3	26.7
703	5.1	17.5	70.4	2.1
705	8.2	11.3	75.4	0.1
8	7.8	11.5	77.0	2.8
801	44.2	0.5	2.8	48.5
803	43.4	0.6	10.5	42.7
9	44.5	0.4	1.9	49.4
901	46.3	0.4	2.5	46.3
902	34.2	0.8	27.2	33.2
10	40.7	0.3	4.0	49.4
1001N	46.3	0.4	1.8	47.2
1001S	47.2	0.6	2.3	46.3
1002	21.7	3.6	56.1	15.2
1101	40.7	0.3	12.5	42.9
1102	44.2	0.4	2.5	47.2
L-1	34.3	4.3	18.6	35.8
L-2	10.0	1.7	81.9	2.2
L-4	22.0	1.1	38.2	32.6
FB-13	43.5	0.4	1.8	46.7
FB-9	31.1	0.8	32.7	29.8
FB-10	3.9	16.6	74.8	0.1
FB-11	6.1	13.1	75.9	Trace
FB-12	44.2	0.4	3.3	46.3

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 5 Temperature: 80° F Weather: Clear

Date Sample Taken: July 14, 1967

Date Sample Analyzed: July 19, 1967

Probe No.	CO_2	O_2	N_2	CH_4
1A	9.0	14.2	75.3	NIL
1B	9.8	13.7	74.8	NIL
1C	4.8	18.1	75.5	NIL
1D	2.5	20.0	75.5	NIL
2D	2.5	20.0	75.5	NIL
3E	2.4	20.3	75.5	NIL
4E	3.0	19.8	75.5	NIL
4F	4.5	19.4	75.5	Trace
3F	2.9	19.8	75.5	NIL
4G	12.0	11.3	75.3	NIL
3G	3.6	18.9	75.3	Trace
3H	10.8	11.8	74.8	Trace
2H	3.5	18.7	75.3	Trace
1J	8.5	14.2	74.8	NIL
6	2.8	19.7	75.3	NIL
7	5.7	15.5	75.5	NIL
8	8.3	13.8	75.3	NIL
9C	21.2	4.2	63.5	7.3
9B	34.8	0.7	24.7	35.8
10B	33.9	1.2	32.5	29.3
10C	22.5	1.9	73.8	0.3
9A	37.5	1.2	21.8	38.4
10A	36.7	1.0	22.5	38.1
12	15.5	8.3	75.5	1.2
11	26.4	1.5	61.1	10.2
13A	20.2	5.3	56.2	18.8
13B	12.5	14.0	60.8	11.5
13C	11.8	14.3	62.2	10.2
13D	12.7	14.2	61.9	10.0
13E	32.4	3.8	31.9	31.8
14	30.3	0.9	41.8	25.7
15E	26.2	4.3	56.2	12.3
17B	5.1	17.7	74.7	Trace
17C	4.6	18.3	74.7	NIL
17D	2.8	19.6	74.7	NIL
17E	4.3	17.1	74.0	NIL
22	4.5	17.7	74.7	NIL
21A	10.6	7.0	79.6	NIL
21B	7.2	6.9	83.0	NIL
21C	7.2	8.9	81.3	NIL
21D	3.2	18.5	74.7	NIL
18	4.2	16.0	68.2	Trace
19	4.3	17.9	71.8	1.0
20	Trace	19.7	73.5	NIL

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 5   Temperature: 75° - 80°   Weather: Warm - clear

Date Sample Taken: January 24, 1968

Date Sample Analyzed: January 30, 1968 and January 31, 1968

Probe No.	CO_2	O_2	N_2	CH_4
1A	5.2	13.7	79.7	NIL
1B	8.0	13.6	76.0	NIL
1C	3.0	17.7	79.9	NIL
1D	0.2	21.2	79.2	NIL
3B	0.3	21.5	78.5	NIL
4E	1.1	20.8	78.6	NIL
4F	1.7	20.0	78.5	NIL
3F	0.8	21.1	78.0	NIL
3G	1.8	19.9	78.5	NIL
4G	11.9	10.4	77.4	NIL
2H	1.1	20.5	79.4	NIL
6	0.7	21.2	79.4	NIL
7	5.6	12.7	83.0	NIL
21A	9.3	8.1	83.5	NIL
21B	6.0	10.0	84.8	NIL
21C	6.7	5.6	89.0	NIL
21D	6.9	6.3	88.0	NIL
9A	35.7	0.5	21.2	39.4
10A	32.2	1.4	32.5	31.2
9B	34.2	1.3	26.8	34.6
9C	22.2	1.2	66.5	9.0
10B	30.0	0.9	45.7	22.0

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 6 Temperature: 70° Weather: Clear and Warm

Date Sample Taken: June 15, 1967 and August 23, 1967

Date Sample Analyzed: June 20, 1967 and August 30, 1967

Probe No.	CO_2	O_2	N_2	CH_4
13B	7.7	15.9	79.0	NIL
12B	21.6	0.7	49.0	30.8
10B	40.0	0.5	23.4	38.0
9B	3.6	16.6	79.5	0.2
3B	2.3	19.2	78.0	NIL
2B	1.5	20.2	78.2	NIL
1A	4.0	18.2	78.0	NIL
2A	1.1	19.2	78.6	NIL
3A	1.8	19.4	79.5	NIL
4A	1.2	20.4	78.2	NIL
5A	0.6	16.6	81.9	NIL
6A	Trace	20.2	78.6	NIL
7A	0.6	20.4	77.5	NIL
8A	1.1	20.1	77.2	NIL
9A	0.1	20.7	77.0	NIL
10A	0.2	20.8	77.5	NIL
11A	0.9	18.9	79.0	NIL
12A	3.1	18.6	76.3	NIL
13A	4.0	19.1	75.6	NIL
14A	1.5	19.3	75.6	NIL
1B	2.9	19.3	73.5	NIL
2B	2.8	19.4	73.5	Trace
3B	2.4	20.0	73.5	NIL
4B	5.0	16.0	70.7	1.8
5B	38.9	0.5	5.9	55.0
6B	24.3	9.0	36.3	30.3
7B	0.5	20.3	77.8	0.4
8B	2.4	19.5	77.0	1.3
9B	3.0	19.5	77.0	NIL
10B	16.5	7.6	75.3	0.6
11B	29.6	6.2	29.5	33.7
12B	11.0	10.9	76.5	Trace
13B	2.6	20.0	75.8	NIL
14B	3.5	18.9	75.3	NIL
15B	4.5	18.1	75.3	NIL
16B	35.2	0.7	29.0	33.7
15A	5.7	16.0	76.5	Trace
16A	4.7	17.3	75.3	NIL
15C	17.2	7.1	75.8	Trace
16C	35.3	0.8	33.0	31.7
14C	3.8	19.1	71.0	4.7

Probe No.	CO_2	O_2	N_2	CH_4
13C	14.2	12.8	48.0	24.0
11C	13.4	11.6	73.5	0.5
10C	9.0	14.8	75.8	Trace
9C	28.3	0.8	68.2	2.2
8C	26.1	8.3	33.5	30.7
7C	43.0	0.2	0.6	53.8
6C	8.7	16.0	69.5	3.0
5C	32.8	4.0	18.0	42.5
4C	21.4	10.0	38.2	27.2
3C	3.2	17.8	65.8	1.4
2C	2.4	18.5	68.2	Trace
1C	2.3	18.6	68.2	Trace
3C	42.3	1.2	12.5	33.2

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 6 Temperature: 55° F Weather: Cool - Overcast

Date Sample Taken: February 8, 1968

Date Sample Analyzed: February 13, 1968 & February 14, 1968

Probe No.	CO_2	O_2	N_2	CH_4
16C	37.6	0.8	14.3	44.2
15C	30.7	0.7	34.5	32.6
13C	41.9	0.3	1.5	52.5
11C	20.1	9.4	56.2	10.9
10C	11.3	13.6	71.0	1.0
9C	36.2	0.6	27.2	32.7
8C	39.3	0.5	16.8	39.3
7C	41.2	0.5	2.4	49.8
6C	8.3	15.5	71.0	0.1
5C	26.1	7.5	28.4	32.7
4C	40.7	0.9	4.0	48.4
3C	42.3	0.7	3.6	47.6
2C	4.7	15.1	75.7	0.1
1C	8.5	8.2	79.7	Trace
1B	0.6	20.0	73.3	Trace
2B	1.4	18.9	73.9	Trace
3B	0.2	20.3	72.3	NIL
3B	1.0	19.7	75.4	NIL
4B	29.5	0.6	16.1	47.2
5B	40.5	0.8	4.1	49.8
6B	38.6	1.1	4.8	48.8
7B	8.6	11.4	56.7	18.0
8B	0.6	19.2	74.7	0.5
9B	10.3	10.4	74.7	0.4
10B	38.6	0.3	2.3	51.1
11B	41.2	0.2	1.1	52.8
12B	16.9	6.3	33.0	37.2
13B	27.2	0.5	10.0	54.2
16B	37.5	0.4	8.7	47.2
14B	15.2	2.0	53.9	23.3
15B	1.5	18.9	73.3	0.1
1A	1.5	19.6	72.8	Trace
2A	0.6	18.9	73.9	Trace
3A	0.8	19.3	73.3	Trace
5A	28.5	3.4	25.9	37.0
6A	12.7	1.5	76.9	5.0
7A	9.0	7.3	79.4	0.4
8A	0.3	20.3	72.8	NIL
9A	NIL	20.7	75.3	NIL
10A	NIL	20.2	73.3	NIL

Probe No.	CO_2	O_2	N_2	CH_4
11A	11.0	5.2	69.8	9.3
12A	0.9	19.1	75.7	NIL
13A	6.5	8.1	78.7	1.6
14A	1.3	19.3	75.7	NIL
15A	2.9	16.2	76.9	NIL
16A	2.7	17.2	76.5	NIL

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 7 Temperature: 80° - 85° Weather: Clear-Hot

Date Sample Taken: August 8, 1967

Date Sample Analyzed: August 17, 1967

Probe No.	CO_2	O_2	N_2	CH_4
1	5.3	16.8	74.0	NIL
2	28.5	1.2	55.0	12.4
3	5.9	16.3	74.0	NIL
4	39.3	1.0	36.3	23.4
5	17.2	7.0	73.5	0.2
6	2.8	19.5	73.5	NIL
7	7.5	14.1	76.6	NIL
8	2.5	20.2	75.3	NIL
9	2.5	20.0	74.6	NIL
10	2.7	19.8	74.6	NIL

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 7 Temperature: 60°F Weather: Cool - Overcast

Date Sample Taken: February 21, 1968

Date Sample Analyzed: March 1, 1968

Probe No.	CO_2	O_2	N_2	CH_4
1	5.4	17.0	74.8	NIL
2	38.6	0.9	16.3	41.0
3	6.6	16.1	73.4	0.2
4	44.9	0.5	7.2	43.8
5	26.7	1.6	60.7	7.7
6	4.1	17.6	75.4	NIL
9	2.2	19.6	74.8	NIL
10	3.0	19.4	74.8	NIL

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 8 Temperature: 65° Weather: Warm, high clouds

Date Sample Taken: May 9, 1967

Date Sample Analyzed: May 15, 1967

Probe No.	CO_2	O_2	N_2	CH_4
1A	41.9	0.9	4.0	52.6
1B	29.7	0.5	27.9	44.8
1C	34.8	0.7	19.3	47.5
2C	43.7	0.2	0.9	56.8
2A	4.3	19.9	78.5	NIL
2D	41.4	0.4	3.6	54.2
2B	38.8	0.3	1.1	55.4
3A	44.5	0.5	2.5	51.2
3B	42.3	0.3	6.3	50.5
4A	39.3	0.4	14.8	45.3
5	3.2	20.1	76.8	NIL
6	15.4	4.7	66.9	10.6
6A	19.5	1.2	56.4	22.5
7A	39.5	0.4	9.9	49.7
7B	43.0	0.3	2.4	56.0
8	42.3	0.5	3.7	55.8
8A	41.5	0.2	2.2	57.4
9A	47.2	0.2	9.6	45.8
9B	41.2	0.2	3.7	55.0
10	35.2	1.0	34.8	30.3
10A	43.5	0.1	1.2	54.2
11A	36.5	0.3	12.4	48.7
12	3.7	19.0	75.2	Trace
13B	24.1	5.8	41.0	27.3
13	23.9	2.5	69.0	2.4
13A	35.5	0.5	15.2	45.0
14	28.8	5.7	24.7	38.5
15A	36.7	0.2	5.2	54.5
16A	23.2	1.0	69.8	4.3
17	8.2	13.7	75.0	Trace
18B	7.0	9.9	80.5	Trace
22A	5.8	15.5	76.3	NIL
19A	28.6	0.8	41.3	30.2
19B	30.2	0.7	30.7	39.5
20A	27.4	1.2	47.0	24.5
20B	27.2	0.8	44.3	27.0
23A	7.5	13.8	77.5	Trace
24A	6.8	14.3	75.5	NIL
25	39.0	0.3	4.1	57.2
25	39.0	0.2	3.3	57.2
27	15.2	11.6	48.9	23.8

Probe No.	CO_2	O_2	N_2	CH_4
27	26.0	5.3	27.3	42.3
26	44.6	0.2	2.0	54.0
26	43.0	0.5	3.2	53.5
28	30.7	0.6	24.4	44.0
28	31.2	0.6	24.4	44.2
2C	39.7	0.3	9.5	48.7
2C	40.5	0.2	9.0	49.3
25	37.8	0.5	4.4	54.3
25	38.4	0.2	3.1	55.0
27	30.7	2.0	16.0	48.5
27	30.7	1.8	16.0	52.8
26	35.5	3.2	13.7	47.3
26	42.6	0.2	1.9	54.8
28	15.6	10.3	49.3	23.6
28	27.3	2.2	29.0	41.8
2C	38.5	0.3	9.6	40.2
2C	38.5	0.3	9.7	50.4

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 8   Temperature: 75°   Weather: Warm - Overcast

Date Sample Taken: September 13, 1967

Date Sample Analyzed: September 20, 1967

Probe No.	CO_2	O_2	N_2	CH_4
1A	18.4	10.6	48.8	22.2
1B	33.9	0.7	28.2	45.0
1C	36.0	0.4	30.7	42.7
2C	36.0	0.8	26.4	42.7
2D	31.3	1.1	38.3	29.3
2B	36.7	0.4	17.7	43.9
3A	37.8	0.68	17.6	43.9
3B	27.7	1.27	57.5	13.5
4A	25.5	1.10	58.9	14.5
5	1.33	18.7	75.6	Trace
6	5.5	17.5	80.0	0.00
6A	9.5	13.0	78.0	Trace
7A	34.5	0.7	19.0	47.5
7B	29.0	4.5	21.9	46.0
8	38.0	0.6	6.4	54.5
8A	37.0	0.7	5.1	56.6
9A	37.0	0.7	19.0	44.5
9B	37.9	0.5	11.6	50.0
10A	39.1	0.3	7.6	52.0
11A	26.2	12.6	49.7	12.0
12	3.0	21.2	76.8	Trace
13B	15.9	7.4	75.5	Trace
13	18.8	5.3	74.0	0.2
13A	31.0	1.2	37.5	31.4
18B	6.7	17.7	75.0	Trace
22A	6.2	17.9	74.0	Trace
19A	8.3	15.5	75.0	Trace
19B	12.8	12.0	73.5	0.0
27	8.4	15.4	69.0	5.7
14	22.6	5.0	32.2	40.5
25	38.0	0.4	5.6	55.5
15A	33.4	0.3	13.3	52.5
20A	12.6	9.8	73.5	0.1
20B	15.9	7.0	74.0	0.0
23A	8.8	15.2	75.0	0.0
24A	7.2	16.3	75.5	0.0
16A	7.9	14.7	76.0	0.0
17	5.9	17.5	75.0	0.0

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 9 Temperature: 82° F Weather: Clear, light breeze, warm

Date Sample Taken: July 24, 1967

Date Sample Analyzed: July 24 & 25, 1967

Probe No.	CO_2	O_2	N_2	CH_4
1	15	12	71	0.0
2	21	6	73	0.0
3	23	2	72	0.8
4	26	1.1	65	5
5	33	0.8	48	17
6	40	0.3	19	42
7	38	0.4	24	37
8	34	1.0	47	19
9	36	0.4	33	30
10	44	0.5	11	45
11	32	0.6	42	27
12	42	0.4	19	41
14	37	0.6	35	26
15	12	11	76	0.0
16	34	0.8	46	20
17	39	0.4	24	37
18	39	0.3	15	46
19	39	0.5	17	45
20	38	0.4	26	33
21	37	0.3	18	43
22	35	0.2	7	58
23	39	0.4	3	57
24	38	0.5	31	29
25	44	0.1	1.5	55
26	38	0.4	20	40
27	31	0.7	38	28
28	37	0.4	19	42
29	36	0.5	29	32
30	34	0.6	35	29
31	39	0.3	18	43
32	34	0.5	35	30
47	33	0.6	26	39
48	36	0.4	24	40
49	33	0.6	32	33
50	37	0.4	21	41
51	30	0.5	29	41
52	36	0.3	19	46
53	38	0.3	11	52
54	30	0.5	28	41
55	34	0.4	17	50

Probe No.	CO_2	O_2	N_2	CH_4
56	35	0.3	16	48
57	31	0.5	30	38
58	29	0.7	47	22
59	36	0.4	25	39
60	37	0.3	18	45
61	28	0.9	56	17
62	4.8	17	77	0.0
63	2.3	20	76	0.0
64	1.2	20	76	0.0

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 9 Temperature: 55° F Weather: Overcast, light showers

Date Sample Taken: November 28, 1967

Date Sample Analyzed: November 30, 1967 and December 1, 1967

Probe No.	CO_2	O_2	N_2	CH_4
1	7	11	81	0.0
2	14	8	76	0.0
3	15	7	76	0.0
4	26	1.5	44	28
5	30	0.3	10	58
6	26	3.0	22	50
7	31	0.3	7	61
8	31	0.3	28	40
9	33	0.4	21	45
10	35	0.1	5.6	60
11	32	0.1	7	63
12	31	0.2	17	54
14	29	0.1	22	48
15	25	0.6	42	32
16	29	0.2	21	52
17	27	0.3	12	63
18	28	0.1	10	64
19	29	0.1	13	58
20	31	0.3	10	61
21	34	0.2	7	59
22	20	3.3	22	53
23	37	0.1	1.2	61
24	33	0.5	18	48
25	38	0.1	3.9	57
26	34	0.8	11	56
27	29	0.4	20	51
28	30	0.3	27	44
29	29	0.5	23	49
30	33	0.3	17	51
31	34	0.1	7	60
32	32	0.3	18	51
33	33	0.3	18	51
34	35	0.2	7	58
35	35	0.1	9	57
36	34	0.1	9	57
38	32	0.1	5.2	62
39	28	0.1	8	66
40	27	0.2	14	59
41	27	0.4	23	50
42	26	0.4	29	47
47	27	0.3	20	55

Probe No.	CO_2	O_2	N_2	CH_4
48	31	0.2	12	59
49	30	0.2	14	57
50	30	0.2	5.4	65
51	28	0.4	15	56
52	26	0.4	29	46
53	29	0.2	17	55
54	26	0.4	26	48
55	22	0.5	41	36
56	22	0.5	41	37
57	16	1.0	68	14
58	20	0.9	62	17
59	25	0.5	35	41
60	23	0.6	48	28
61	17	3.4	78	0.1
62	4.5	18	77	0.0
63	3.6	18	77	0.0
64	1.6	19	79	0.0
66	25	0.5	33	44
67	18	0.4	61	20
68	5.3	14	79	0.0

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 10 Temperature: 70°F Weather: Clear

Date Sample Taken: October 15, 1967

Date Sample Analyzed: October 16, 1967

Probe No.	CO_2	O_2	N_2	CH_4	H_2S
1	32.4	0.5	24.7	43.3	0.1
2	10.2	6.0	74.5	0.1	0.1
3	34.9	0.1	3.9	59.3	0.1
4	32.0	2.3	23.2	42.3	Trace
5	7.8	15.0	74.0	0.7	0.00
6	20.9	1.0	70.5	6.2	Trace
7	15.9	6.7	75.5	Trace	Trace
8	23.0	5.2	47.0	23.4	Trace

GAS ANALYSIS DATA SHEET

(PERCENT)

Site No.: 10 Temperature: 67°F Weather: Clear

Date Sample Taken: November 4, 1967

Date Sample Analyzed: November 5, 1967

Probe No.	CO_2	O_2	N_2	CH_4	H_2S
1	31.4	0.5	30.0	40.5	0.0
2	10.1	11.8	79.0	Trace	0.0
3	35.9	0.3	8.1	59.5	0.0
4	16.6	9.0	58.0	14.9	0.0
5	5.3	16.0	77.0	0.8	0.0
6	19.8	1.3	73.0	5.5	0.0
8	17.0	4.6	77.0	0.2	0.0

APPENDIX D

"WEATHERGARD FIBERSEAL LINER"
(FIBER REINFORCED SEALER)

(Verbatim from Weathergard Products Newsletter)

"WEATHERGARD FIBERSEAL LINER" is a moisture impervious lining for containment of water in reservoirs, canals, irrigation ditches, storm drains, etc. It is composed of combining specifically designed mineral filled "WEATHERGARD ASPHALT" and a selected fiber mesh. This fabricated sealer will form a reinforced continuous membrane over the prepared soil surfaces or previously lined areas. "WEATHERGARD FIBERSEAL LINER" is a positive monolithic construction. Having the mesh in the center of the fabricated liner will permit it to flex with equal ease in any direction without establishing undue stresses. The mesh is the most favorable position for maximum sheer strength. It is in a protected position with respect to weathering or damage. The mineral filled asphalt is introduced as a filler to lend bulk or depth to the coating and serve as an abrasion deterrent. It also gives stability to the membrane and assists in preventing sag on steep slopes.

The asphalt used in "WEATHERGARD FIBERSEAL LINER" is of a high melting point base to insure a minimum of sag at elevated temperatures and also maintain resilience in low temperatures to resist cracking and will permit it to follow the subgrade if any settling or shifting that may occur. See SPECIFICATIONS FOR MATERIAL. The mesh is of a large weave as noted in the specifications and permits the desired amount of mineral filled asphalt to be placed within the mesh openings without excessive build-up.

When used on embankments for erosion control, the "WEATHERGARD FIBERSEAL LINER" will eliminate much of the damage caused by foot traffic to which these areas are often subjected. Economics, durability and ease of application are the main factors which make "WEATHERGARD FIBERSEAL LINER" the practical way to solve sealing problems.

MATERIALS

"WEATHERGARD FIBERSEAL LINER" is a fiber reinforced asphalt liner, fabricated on the job site.

"WEATHERGARD FIBERSEAL LINER" herein referred to is manufactured by MACMILLAN RING-FREE OIL CO., INC., 615 So. Flower Street, Los Angeles, Calif. MA 2-2241.

"WEATHERGARD FIBERSEAL LINER" shall consist of the following products:

A. "WEATHERGARD FIBERSEAL MESH" is a natural or synthetic heavy mesh of a uniform open weave of undyed and unbleached single yarn averaging 130 pounds per spindle of 14,400 yards. The yarn shall be of a loosely twisted construction having an average twist of not less than 1.6 turns per inch, and shall not vary in thickness by more than one-half its normal diameter. It shall have: 78 warp ends per width of cloth approximately 1/4 inch in diameter. The mesh is impregnated with a bituminous base waterproofing treatment.

B. "WEATHERGARD FIBERSEAL PRIME COAT" is Rapid-Curing Liquid Asphalt and shall adhere to the following specifications:

Kinematic Visicosity @ 140°F, CS'	70-140
Distilation (% total distillate to 680°F)	
To 374°F	10 Min.
To 437°F	50 Min.
To 500°F	70 Min.
To 600°F	85 Min.
Residue from distillation to 680°F., Volume % by difference	55 Min.
Tests on Residue from distillation	
Penetration 77°F, 100g. 5 sec.	40-50
Ductillity, 77°F, CMS	100 Min.
Solubility in Carbon Tetrachloride %	99.5 Min.
Water %	0.2 Max.

Fiberseal Coating materials prior to mixing shall conform to the following requirements:

A. Asphaltic emulsion shall be 50-60 penetration asphalt SS-1h mixing type conforming to the following provisions:

Saybolt Furol Viscosity @ 77°F., sec.	20-100
Residue by Distillation %	57-62
Settlement, 5 days, %	3 Max.
Sieve Test (Ret. on #20) %	0.10 Max.
Tests on Residue	
Penetration @ 77°F., 100g. 5 sec.	50-60
Soluble in Carbon Tetrachloride %	97.5 Min.
Ductility @ 77°F. CM	40.0 Min.

B. Aggregate shall consist of rock dust and plaster sand. The percentage composition by weight of the aggregate shall conform to the following grading:

Seive Size	Percent passing
No. 4	100
No. 8	95-100
No. 16	60-90
No. 30	40-65
No. 200	8-15

Proportioning - The aggregate asphaltic emulsions and water shall be proportioned approximately as follows:

Aggregates (dry weight)	1,500 pounds
Asphaltic emulsion (SS-1h)	46 gallons
Water, including moisture in aggregates	10 gallons

The aggregates, asphaltic emulsion and water shall be mixed in continuous pugmill mixer or rotating drum truck mixers.

"WEATHERGARD FIBERSEAL SEAL COAT" is a highly resilient, specially air-refined asphalt. This product has extremely good recovery properties and maintains these characteristics over long exposure times. When used as an adhesive, this product will provide excellent temperature susceptibility, along with a relatively high softening point.

Specifications:

	Minimum	Typical	Maximum
Softening point, °F.	190		200
Penetration @ 32°F., d.m.m.	30		
" @ 77°F., d.m.m.	50		60
" @ 115°F., d.m.m.			120
Ductility @ 77PF., C.M.	3.5		
Solubility CCl_4, %			1.0
Loss on heating, %			1.0
Penetration after loss, % of original	60.0		
Specific gravity	1.02		1.03
Pounds per gallon		8.5	
Flash (C.O.C.), °F.	425		

APPLYING "WEATHERGARD FIBERSEAL LINER"

1. After the area to be lined with "WEATHERGARD FIBERSEAL LINER" has been brought to a final grade as per specified requirements, suitable weed sterilants should be introduced into the surface soil.

2. Immediately following this application "WEATHERGARD FIBERSEAL MESH" shall be spread over the entire area in an even, wrinkle-free layer. Four (4) inch overlaps are specified at the joints of the mesh. The mesh shall be lain so that its joints are overlapped in a downstream construction method. Wire anchors shall be placed at 18 inch intervals along the overlaps to secure the joints and intermittently along the length of the mesh panel where necessary to secure it to a cloped surface. If "WEATHERGARD FIBERSEAL LINER" is being applied over concrete or asphaltic concrete surfaces, hog rings should be used in lieu of anchors to secure the "WEATHERGARD FIBERSEAL MESH" at the overlap joints.

3. When the "WEATHERGARD FIBERSEAL MESH" has been placed and secured over the entire surface to be lined, the first coat of "WEATHERGARD FIBERSEAL PRIMER" shall be applied at materials rate of 3/4 gallon per square yard. The "WEATHERGARD FIBERSEAL COATING" shall be squeegeed on the surface in a uniform continuous membrane at a recommended rate of six square feet per gallon of coating.

4. After the "WEATHERGARD FIBERSEAL COATING" has cured for at least 72 hours, an application of "WEATHERGARD FIBERSEAL SEAL COAT" shall be sprayed or mopped over the "WEATHERGARD FIBERSEAL COATING" in such an application that the membrane shall be continuous and without any breaks in its surface area. The "WEATHERGARD FIBERSEAL SEAL COAT"

material shall be heated and applied at a temperature of approximately 450°F. The rate of application will average 2 1/2 square feet of surface area per 1 pound of sealing material.

APPENDIX E

GLOSSARY

Molecular Diffusion - "Just as the molecules of a gas tend to fill any region available to the gas, any particular species of molecules in a fluid will tend to assume a uniform distribution throughout the region available to them. The movement of these molecules seeking uniform distribution is the phenomenon known as diffusion. Since diffusion is always a result of a concentration gradient and the molecules move toward the more random condition, the entropy of the system increases and thus diffusion is a spontaneous process. The rate of diffusion depends primarily upon the molecular velocities and distance traveled between collisions. Diffusion, therefore, is more rapid at high temperatures, at low pressures, and for smaller molecules. For the same reasons it is obvious that diffusion in gases is much more rapid than in liquids." (Reference 2)

Coefficient of Molecular Diffusion, D_m - The proportionality factor in the Fick's First Law:

$$F = -D_m \frac{\partial c}{\partial x}$$

which states that the rate of flux of gas is proportional to concentration gradient. Coefficient of molecular diffusion is therefore the effective flux of gas for a unit concentration gradient through a unit area and has the dimension L^2T^{-1}.

Convective Dispersion - When a pulse of trace component is introduced in the path of a gas flowing through a porous medium, this pulse will undergo spreading due to the difference between flow velocities in various pores of the media and due to the differences between dynamic flow characteristics in each pore. This spreading, independent of molecular diffusion, is considered as convective dispersion.

Coefficient of Diffusion Dispersion, D - The proportionality constant in the generalized Fick's formula which represents the combined effect of molecular diffusion and convective dispersion of one gas into another gas (or other gases). This coefficient also has the dimension L^2T^{-1}.

Concentration Gradient - The decrease in gas concentration per unit distance in a given direction. It has the dimension L^{-1} or ML^{-4}.

Pressure Gradient - The decrease in pressure per unit distance in a given direction. It has the dimension FL^{-3}.

Coefficient of Permeability, K - A proportionality constant in Darcy's Law,

$$Q = -\frac{K}{\mu} \frac{\partial P}{\partial x}$$

which states that the convective flow of a gas is proportional to pressure gradient. $K' = \frac{K}{\mu}$ can also be used as this proportionality constant. K has the dimension L^2.

APPENDIX F

REFUSE GAS BURNERS

The burning of refuse-produced gas is the most efficient means of its disposal. To accomplish this, a system of gas collection pipes buried within a sanitary landfill are usually required and, depending upon the individual site, one or more burners may be needed. The technical details associated with various types of burners, each suited for a specific condition and capacity, are discussed in this appendix.

Because of variation in gas production and the composition of the gas, intermittent operation conditions prevail for most burners. For this reason it is advantageous to collect the refuse gas, if possible, at one burner. To overcome the difficulties of an interrupted gas supply, pilot flames and/or automatic ignition can be used.

The air required (approximately two to five times the gas volume), for mixing with the gas is one of the major controls in the combustion process; therefore, the more elaborate afterburners, as used in industrial plants, have been considered herein in addition to the commonly used tiki-type burners. The afterburners are also considerably more efficient than the open flame burners and therefore minimize air pollution problems.

Three types of burners, best suited for refuse gas disposal systems, are discussed herein:

(1) Tiki-type burners which essentially consist of a vertical pipe that serves as a mixing device and has slit-ports for the introduction of air; ignition is manual.

(2) Waste gas burners, commonly used for burning excess sewage gases.

(3) Vertical gas-fired afterburners as used for burning odorous or toxic gases from industrial plants.

TIKI-TYPE BURNERS (with open flame)

Typical tiki-type burners are shown in Figure V-1. This type of burner usually consists of a three or four-inch vertical pipe perforated as necessary along its length for air entrance. The lower portion of the pipe must, at least, reach a layer of refuse in the fill. The height of the burners above finished fill grade can vary from 10 feet to 20 feet, depending upon safety requirements at particular locations. Gas can enter the burner pipes either directly by perforating the lower portion of the pipe that is below grade, or indirectly, by installing the vertical pipes at the ends, and/or at any desired intermediate point, of horizontal collection pipes buried below grade in a gravel trench. The latter method of installation provides better control of refuse gases and allows the vertical burner pipes to be located away from permanent structures or other improvements.

Ignition of the tiki-type burner can be manual or can be by means of a continuous pilot flame, similar to the waste gas burners described hereinafter. The pilot flame can be either natural gas, if available, or "bottled gas" installed at the site. Because of the likelihood of interruption in the refuse gas supply, it is recommended that tiki-type burners have pilot flames so that maximum benefit is derived from the burner installation.

Tiki-type burners will operate more effectively if some type of burner pot, vent, or wind diffuser is installed at the top of the vertical stack. This provides a forced-draft to enhance refuse-gas flow and also provides blowout protection for the pilot flame.

A typical trench-collection control system with vertical risers for tiki-type burners, as proposed for Site No. 8, is shown in Figure V-9. A simple tiki-type burner is shown in Figure F-1 of this appendix. Because tiki-type burners may be constructed in a variety of forms, with varying costs, no preliminary estimates of cost are included for them in this discussion.

WASTE GAS BURNERS (forced draft burner with open flame)

A typical waste gas burner (Figure F-2) consists of a two to six-inch diameter pipe for conveying the gas, a one-half-inch to one-inch pipe for the pilot flame, an enclosing support pipe, and the steel burner pot. This type of burner is used extensively at sewage treatment plants with satisfactory results.

In order to supply the pilot flame, butane gas cylinders could be installed at a safe distance (25 to 50 feet) from the burner. The burners could be installed without any flow regulation equipment, although such equipment (flame trap and a manometer) may be added if operational experience indicates the need. The smaller size burners, capacity of 2,000 to 5,000 cubic feet per hour (cf/hr), appear to provide sufficient capacity for the anticipated operations.

Following is a preliminary cost estimate for a typical forced draft burner with 0.5 in pressure:

Capital Cost

Waste burner (4,500 cf/hr, 3-inch diameter)	$ 250
Butane gas cylinders (initial installation)	100
Installation	200
Subtotal	$ 550
Technical services and contingencies (30%)	165
Total Capital Cost	$ 715

Annual Cost

Amortization (30 yrs @ 5%)	$ 47
Fuel for pilot flame	250
Operation and maintenance (10 man days/year-for each site)	300
Total Annual Cost	$ 597

AFTERBURNER

Several types of vertical gas-fired afterburners are available commercially. One, the "Meddick Afterburner," has been used extensively in the Los Angeles area.

This type of burner, as shown in Figure F-3, provides efficient mixing of the gas with air, and almost complete combustion. It requires sophisticated control equipment, and either an electrical energy supply for automatic ignition or butane gas system to provide a continuous pilot flame. The pilot flame appears to be more dependable and less costly, and is, therefore, recommended for use. Also, the afterburner system has adequate capacity to meet the requirements for large disposal sites.

Following is a preliminary cost estimate for the Meddick Afterburner with Pilot Flame:

Capital Cost

Complete unit, including burner	$ 500
Controls	150
Butane gas cylinders	100
Installation	250
Subtotal	$1,000
Technical service and contingencies (30%)	300
Total Capital Cost	$1,300

Annual Cost

Amortization (30 yrs @ 5%)	$ 85
Fuel	250
Operation and maintenance (10 man-days/year)	300
Total Annual Cost	$ 635

LIST OF REFERENCES

1. "Municipal Incineration," University of California, Berkeley. Engineering Research, Series 37, Issue 6.

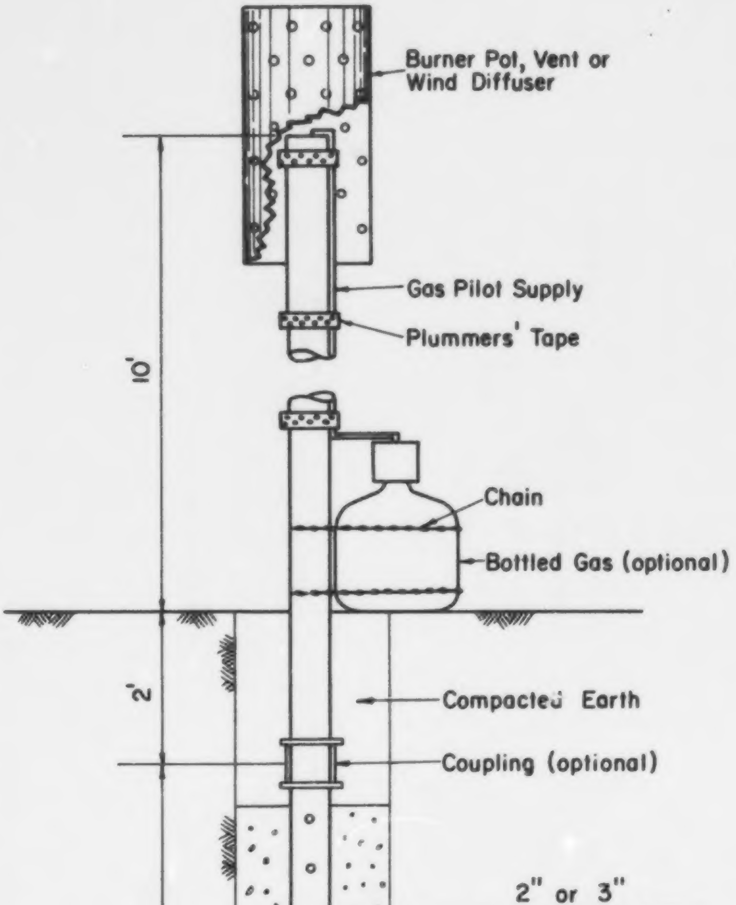
2. "North American Combustion Handbook," North American Manufacturing Company, Cleveland, Ohio.

3. "Fuels and Fuel Burners," K. Steiner, McGraw Hill Book Company, 1946.

4. "Fuels and Combustion Handbook," Johnson and Auth, McGraw Hill Book Company, 1951.

5. "Gas Safety Equipment," Pacific Flush Tank Company, Bulletin No. 321.

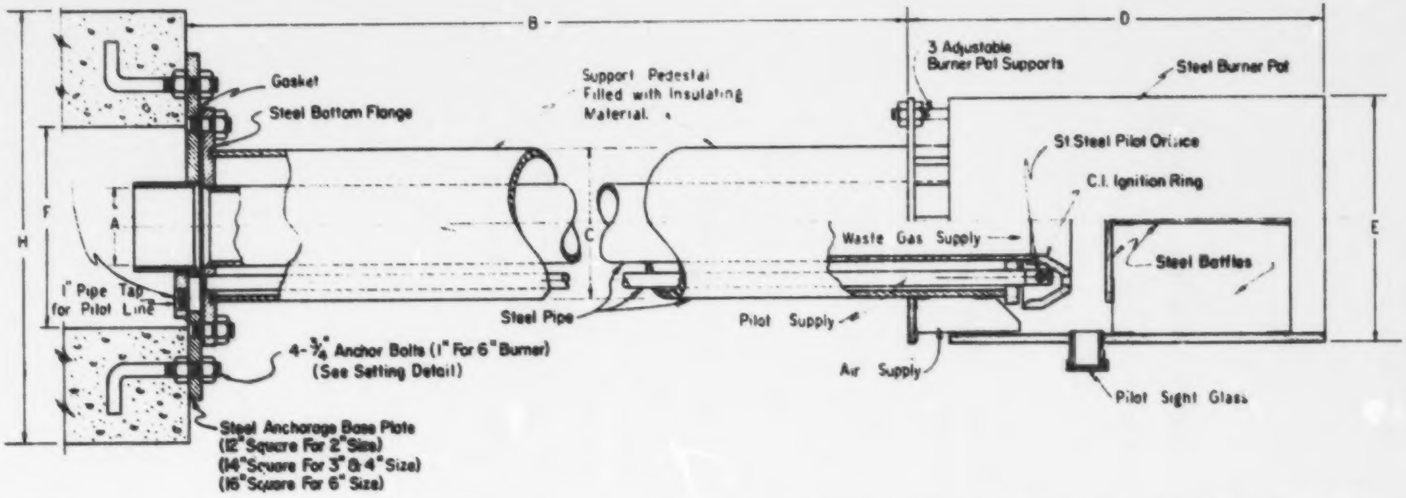
FIGURE F-1


Burner Pot, Vent or Wind Diffuser
Gas Pilot Supply
Plummers' Tape
10'
Chain
Bottled Gas (optional)
2'
Compacted Earth
Coupling (optional)
2" or 3" Perforated Steel Pipe
48'
#2 Gravel
2'

GAS CONTROL DEVICE
VERTICAL WELL TYPE

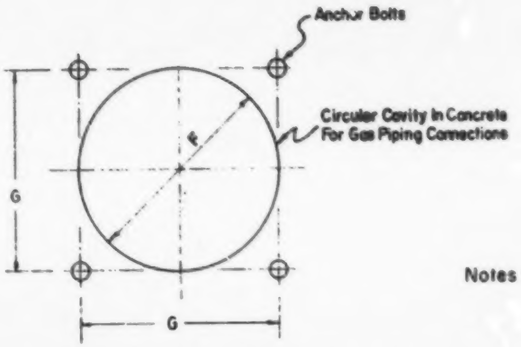
ENGINEERING - SCIENCE, INC.

FIGURE F-2


B
D
E
F
H
A
C
3 Adjustable Burner Pot Supports
Steel Burner Pot
Support Pedestal Filled with Insulating Material
Gasket
Steel Bottom Flange
St Steel Pilot Orifice
C.I. Ignition Ring
Waste Gas Supply
Steel Baffles
1" Pipe Tap for Pilot Line
Steel Pipe
Pilot Supply
Air Supply
Pilot Sight Glass
4-¾" Anchor Bolts (1" For 6" Burner) (See Setting Detail)
Steel Anchorage Base Plate (12" Square For 2" Size) (14" Square For 3" & 4" Size) (16" Square For 6" Size)

BURNER SIZE	A	B	C	D	E	F	G	H	CAPACITY CFH @ ½"	WEIGHT LBS.
2	2"	6-0	6⅝"	1'-9"	12¾"	10½"	9½"	2'-0"	2000	400
3	3"	6'-0"	8⅝"	2'-0"	14"	11"	11½"	2'-0"	4500	540
4	4"	6'-0"	8⅝"	2'-0"	14"	12"	11½"	2'-4"	9000	560
6	6"	10'-0"	10¾"	2'-9"	20"	14½"	13½	2'-6"	20000	1200

Note: F = Max. Diameter
H = Min Side For Square Pier


Anchor Bolts
Circular Cavity In Concrete For Gas Piping Connections
G
G
℄

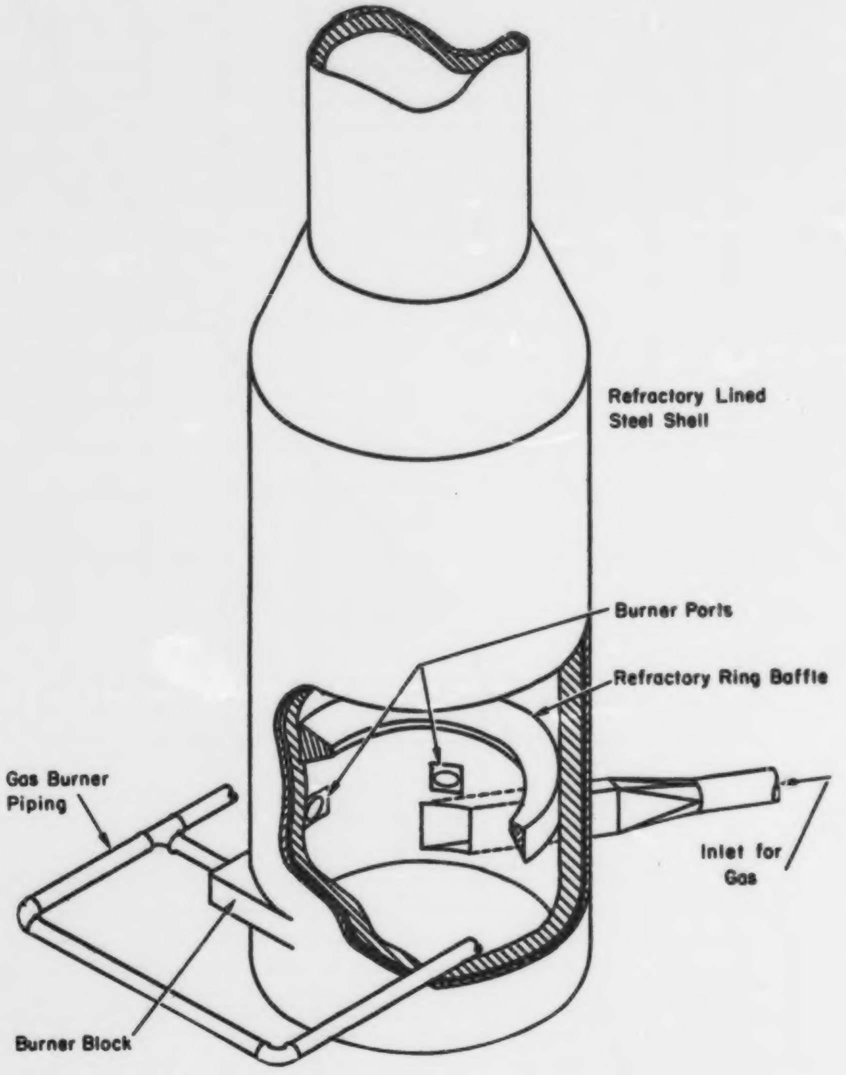
ANCHOR BOLT SETTING

Notes: 1. Waste line and pilot line must be sloped to accessible drip trap and should be below frost line.

2. Drawing "Courtesey of PFT Co."

WASTE GAS BURNER
PEDESTAL TYPE

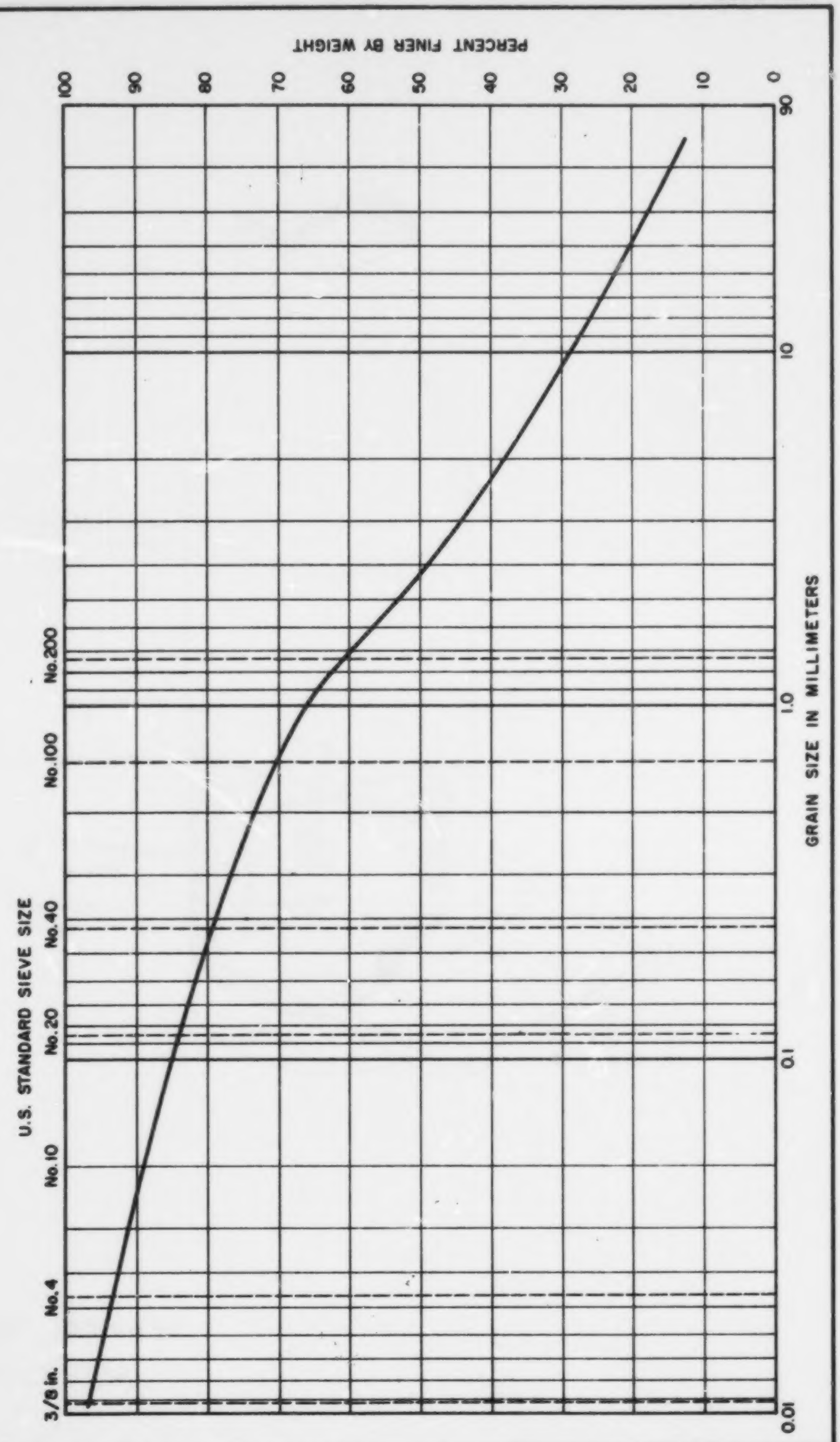
FIGURE F-3


Refractory Lined
Steel Shell
Burner Ports
Refractory Ring Baffle
Gas Burner
Piping
Inlet for
Gas
Burner Block

VERTICAL GAS-FIRED
AFTERBURNER

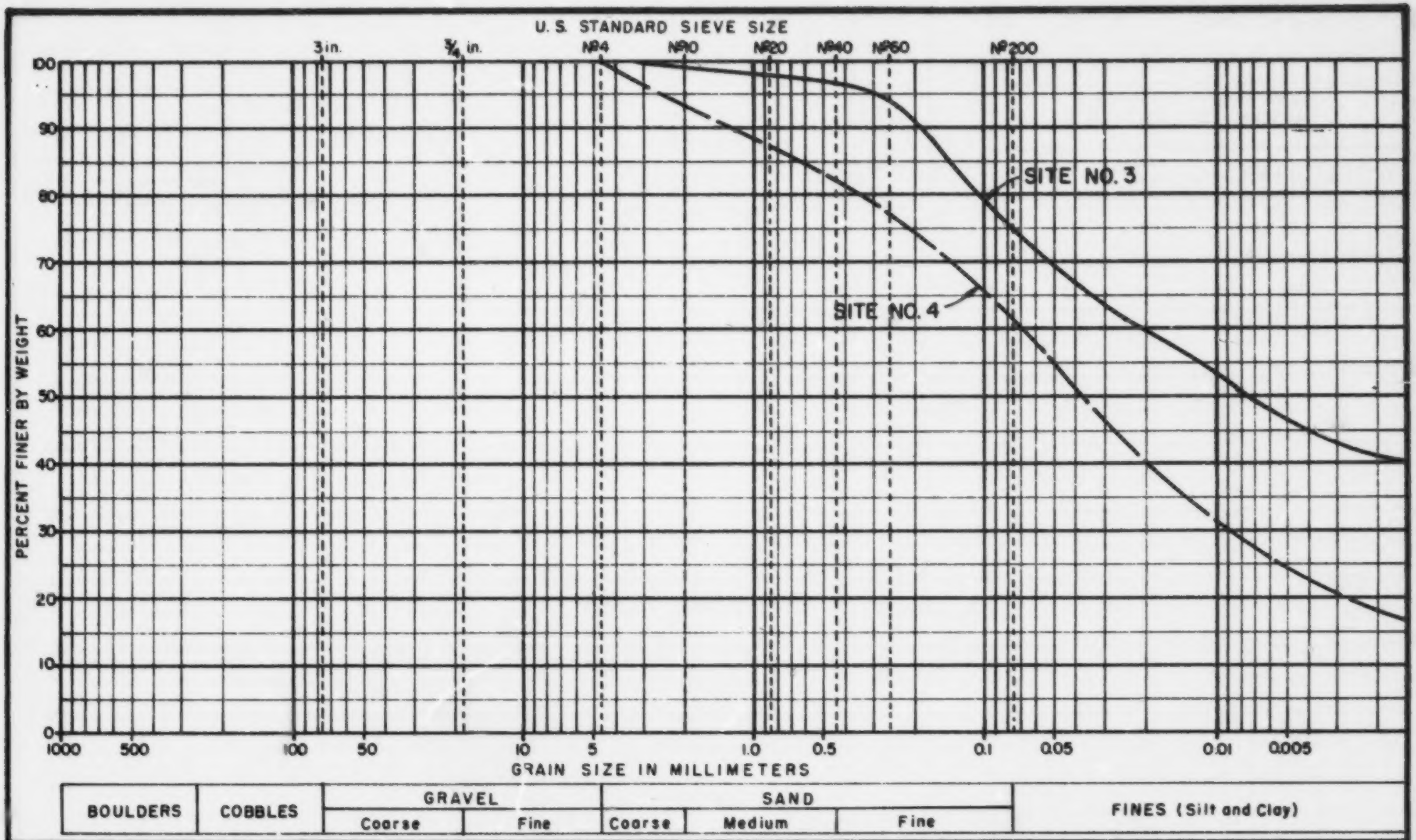
FIGURE III-1

GRAIN SIZE DISTRIBUTION - SITE NO. 2-A



ENGINEERING-SCIENCE, INC.

FIGURE III-2



Site No.	Elev. or Depth	Unified Soil Class.	Description	Nat. Water	LL	PL	PI	SG	Dry Dens.	Moisture
3		CL	Silty Clay					2.62	115.5	11.1
4		ML	Sandy Silt					2.56	101.5	14.8

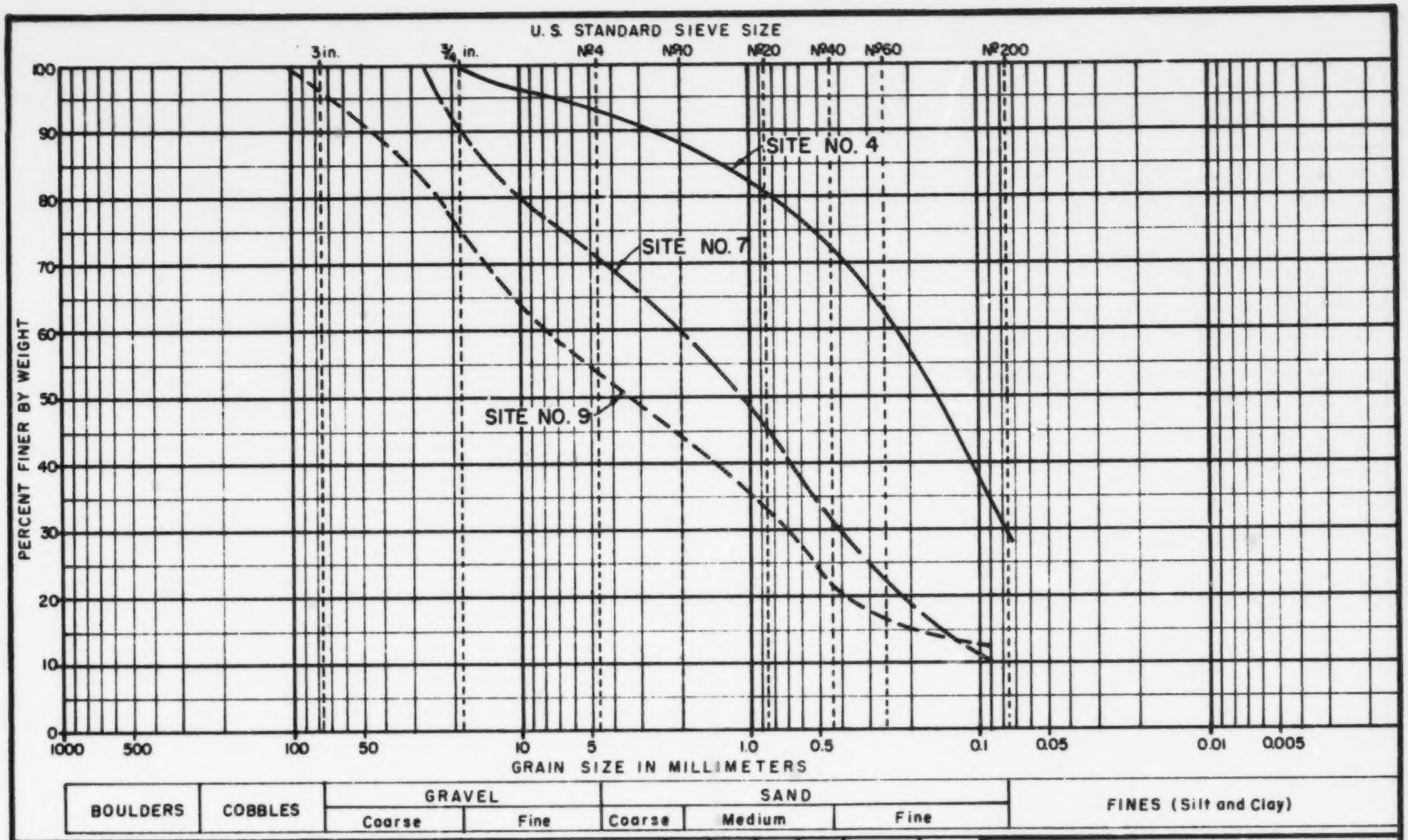
GRAIN SIZE DISTRIBUTION

MOORE & TABER
Engineers — Geologists

Project L.A. County Disposal Study

By BJL
Date 10-17-67

FIGURE III-3



Site No.	Elev. or Depth	Unified Soil Class.	Description	Nat. Water	LL	PL	PI	SG	Dry Dens.	Moisture
4		SM	Silty Sand						110.5	7.3
7		SW/SM	Gravelly Sand						103.5	7.8
9		GW/GM	Gravel-Sand-Silt Mixture						98.2	3.2

GRAIN SIZE DISTRIBUTION

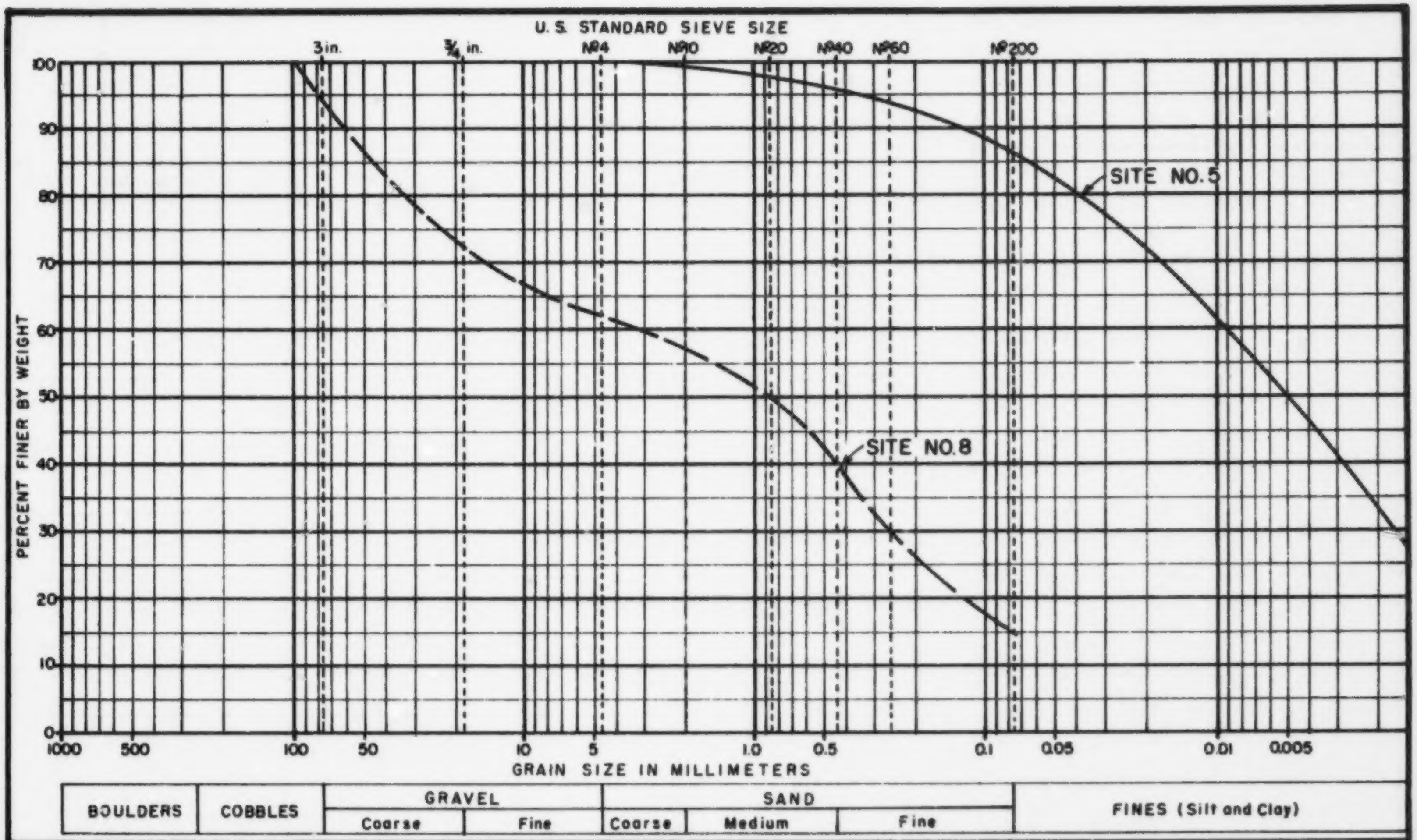
MOORE & TABER
Engineers — Geologists

Project L.A.County Disposal Study

By BJL

Date 10-17-67

FIGURE III-4



Site No.	Elev. or Depth	Unified Soil Class.	Description	Nat. Water	LL	PL	PI	SG	Dry Dens.	Moisture
5		CL	Silty Clay(diatomaceous)					2.40	44.4	16.0
8		SM	Gravelly Sand with Silt					2.70	109.5	4.4

GRAIN SIZE DISTRIBUTION

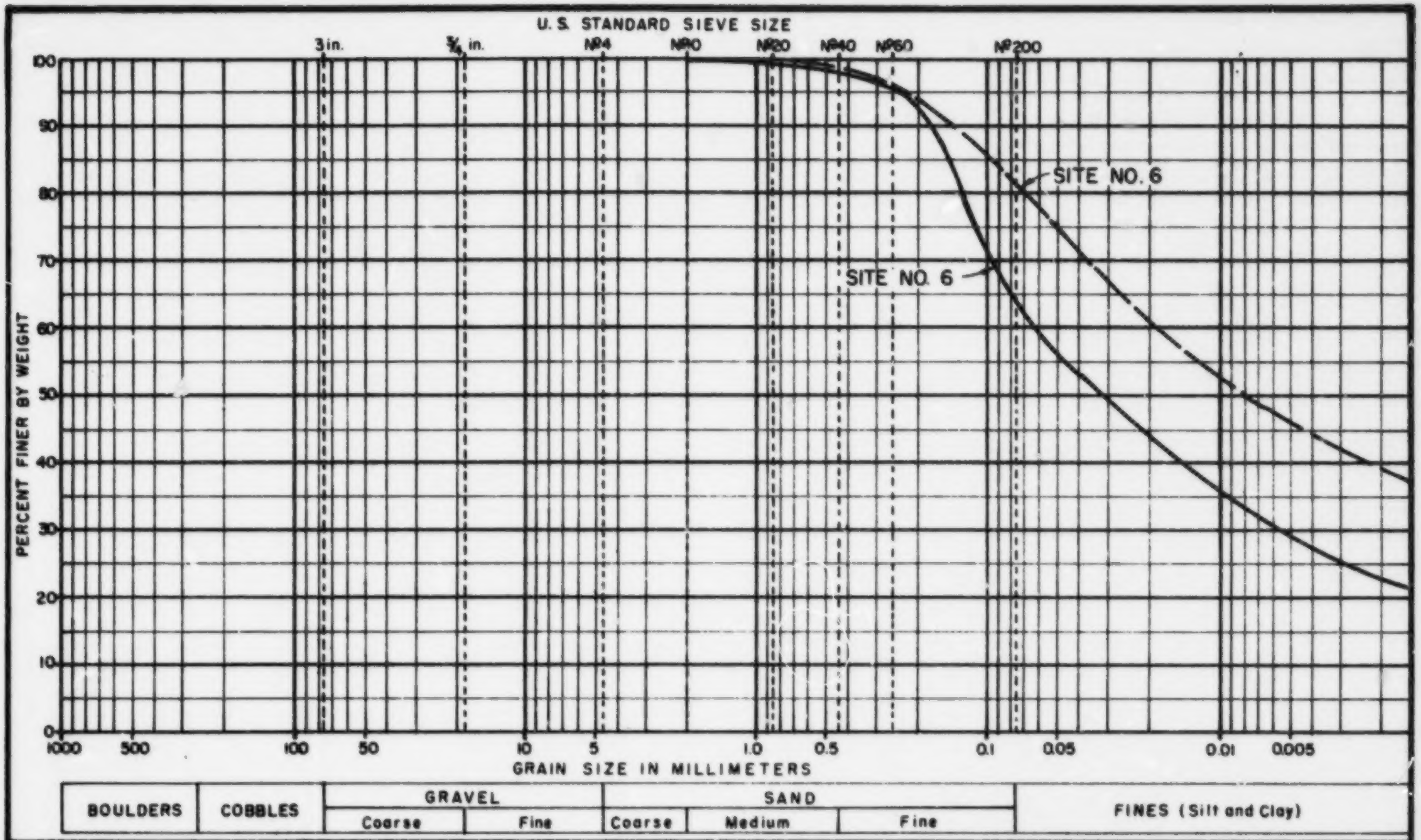
MOORE & TABER
Engineers — Geologists

Project L.A. County Disposal Study

By BJL

Date 10-17-67

FIGURE III-5



Site No.	Elev. or Depth	Unified Soil Class.	Description	Nat. Water	LL	PL	PI	SG	Dry Dens.	Moisture
6		ML	Sandy Silt					2.63	115.0	19.6
6		CL	Silty Clay					2.42	86.3	14.5

GRAIN SIZE DISTRIBUTION

MOORE & TABER
Engineers — Geologists

Project L.A.County Disposal Study

By BJL

Date 10-17-67

GAS COLLECTION ASSEMBLY

(No scale)

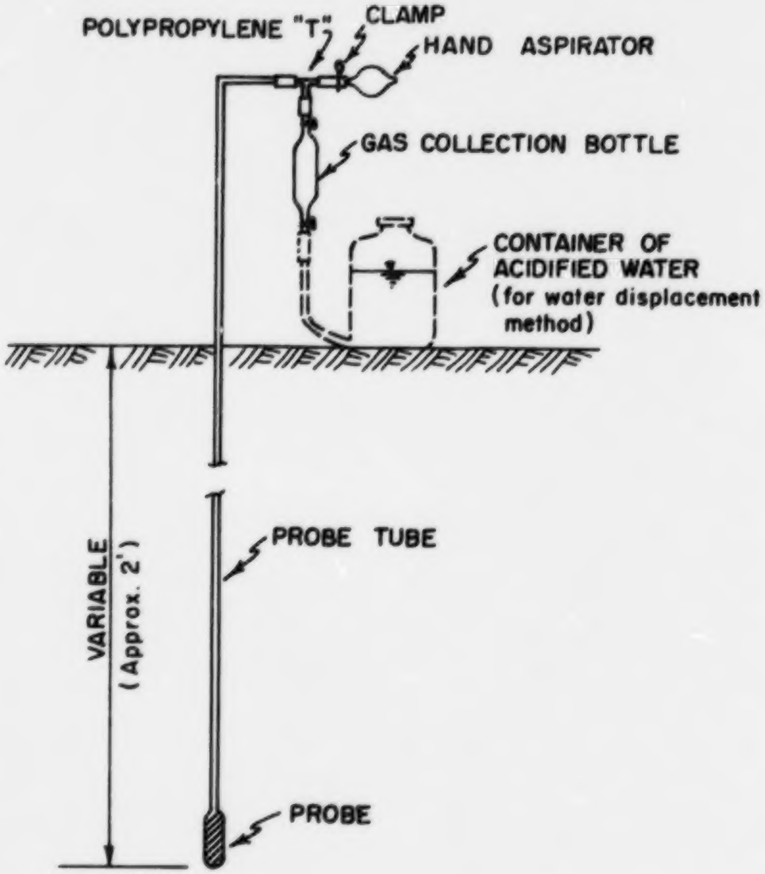
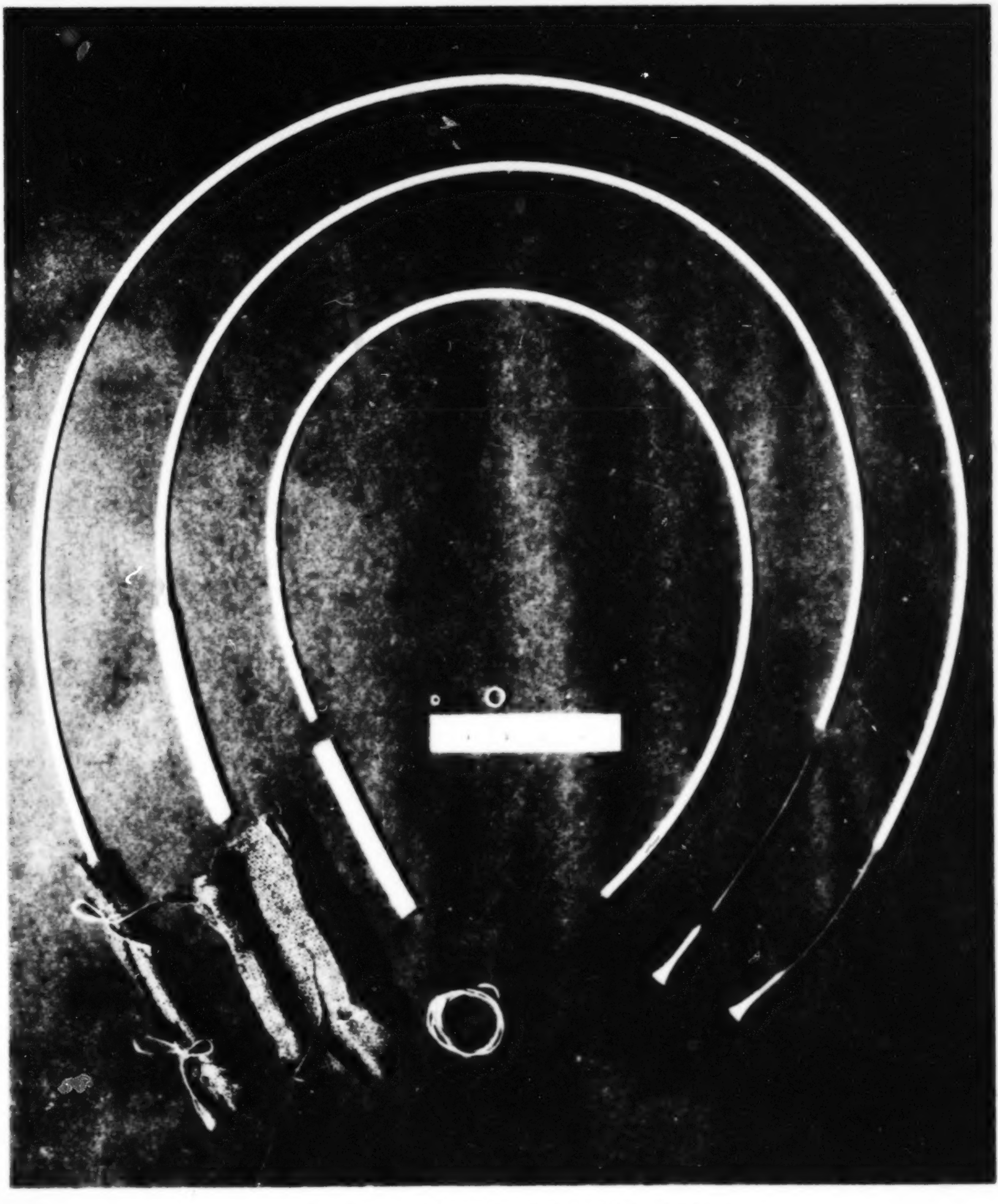

POLYPROPYLENE "T"
CLAMP
HAND ASPIRATOR
GAS COLLECTION BOTTLE
CONTAINER OF ACIDIFIED WATER (for water displacement method)
PROBE TUBE
VARIABLE (Approx. 2')
PROBE

FIGURE III - 7

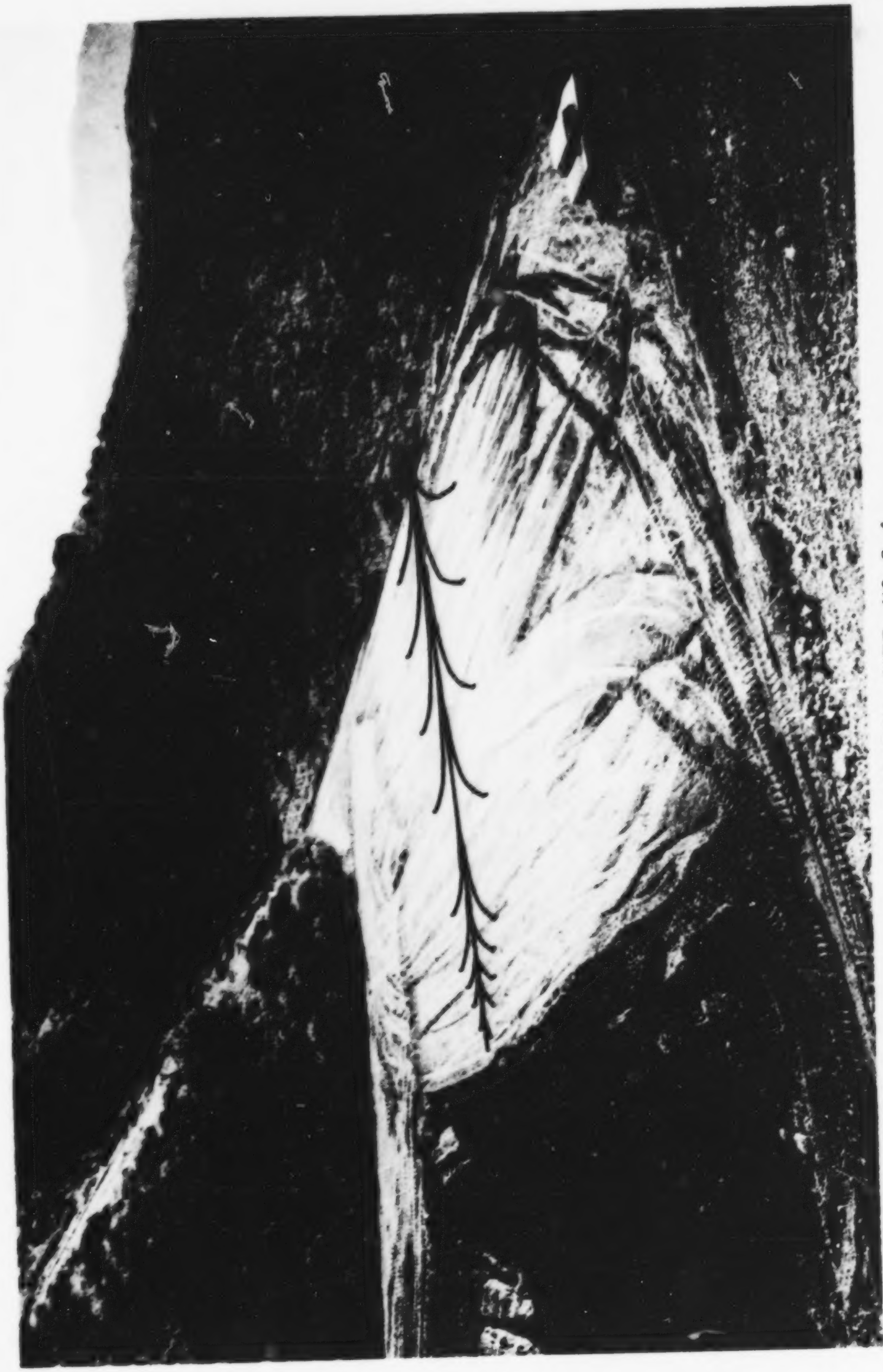


TYPICAL DISASSEMBLED GAS PROBE

RESEARCH SITE NO. 2
Device on dozer ripper tooth for installing gas probe tubing on long horizonal runs.

RESEARCH SITE NO. 2
Installing plastic tubing for gas probes in earth face.

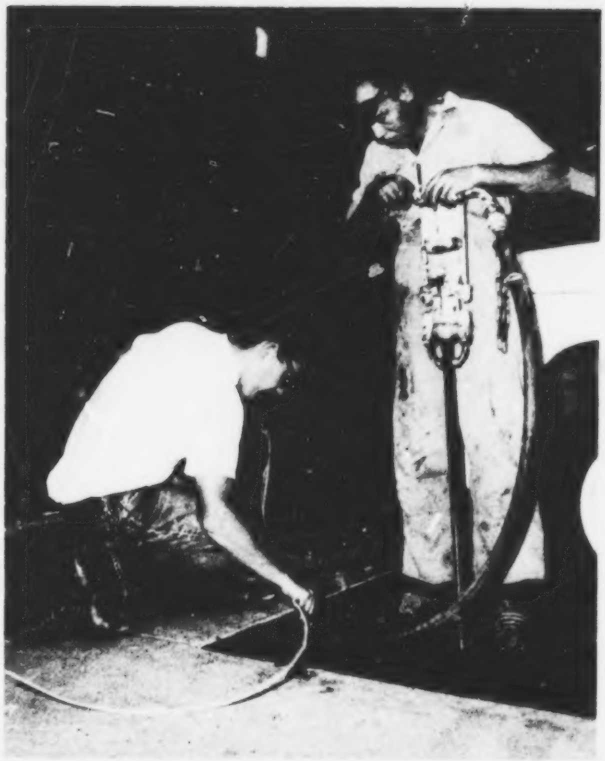
FIGURE III - 9



RESEARCH SITE NO. 2-A

Gas probe and tubing layout at intermediate stage of dike construction.

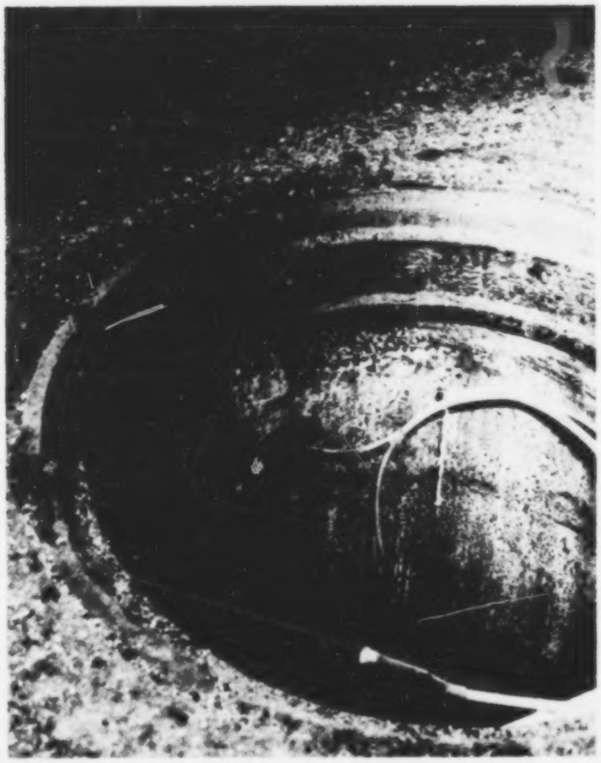
FIGURE III - 10



RESEARCH SITE NO. 1
Installing gas probe beneath asphalt paved area.

RESEARCH SITE NO. 4
Drilling hole for gas probe installation.

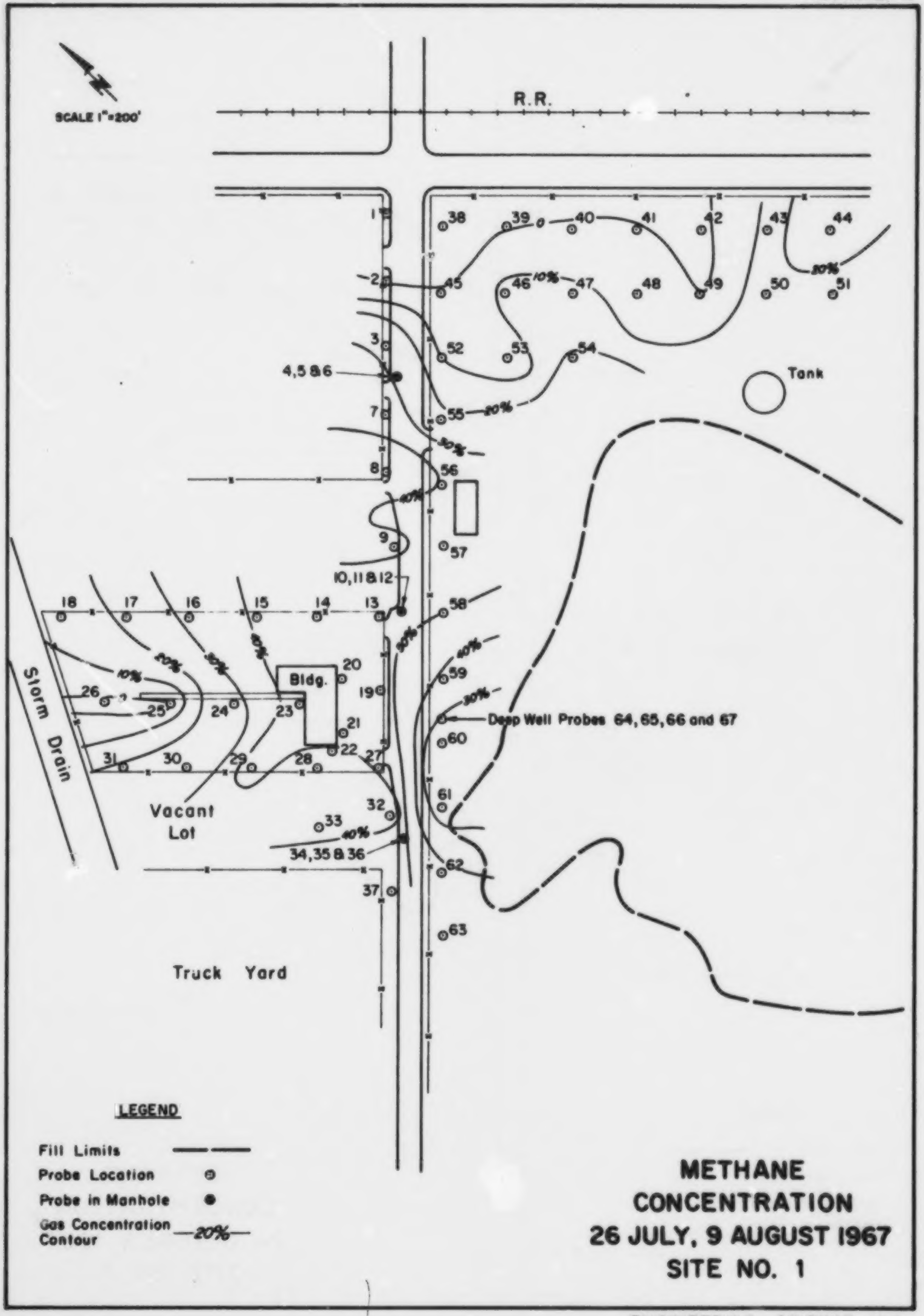
FIGURE III-11



TYPICAL GAS PROBE INSTALLED THROUGH WALL OF SEWER MANHOLE.

WITHDRAWING SAMPLE FROM GAS PROBE INSTALLED THROUGH WALL OF SEWER MANHOLE.

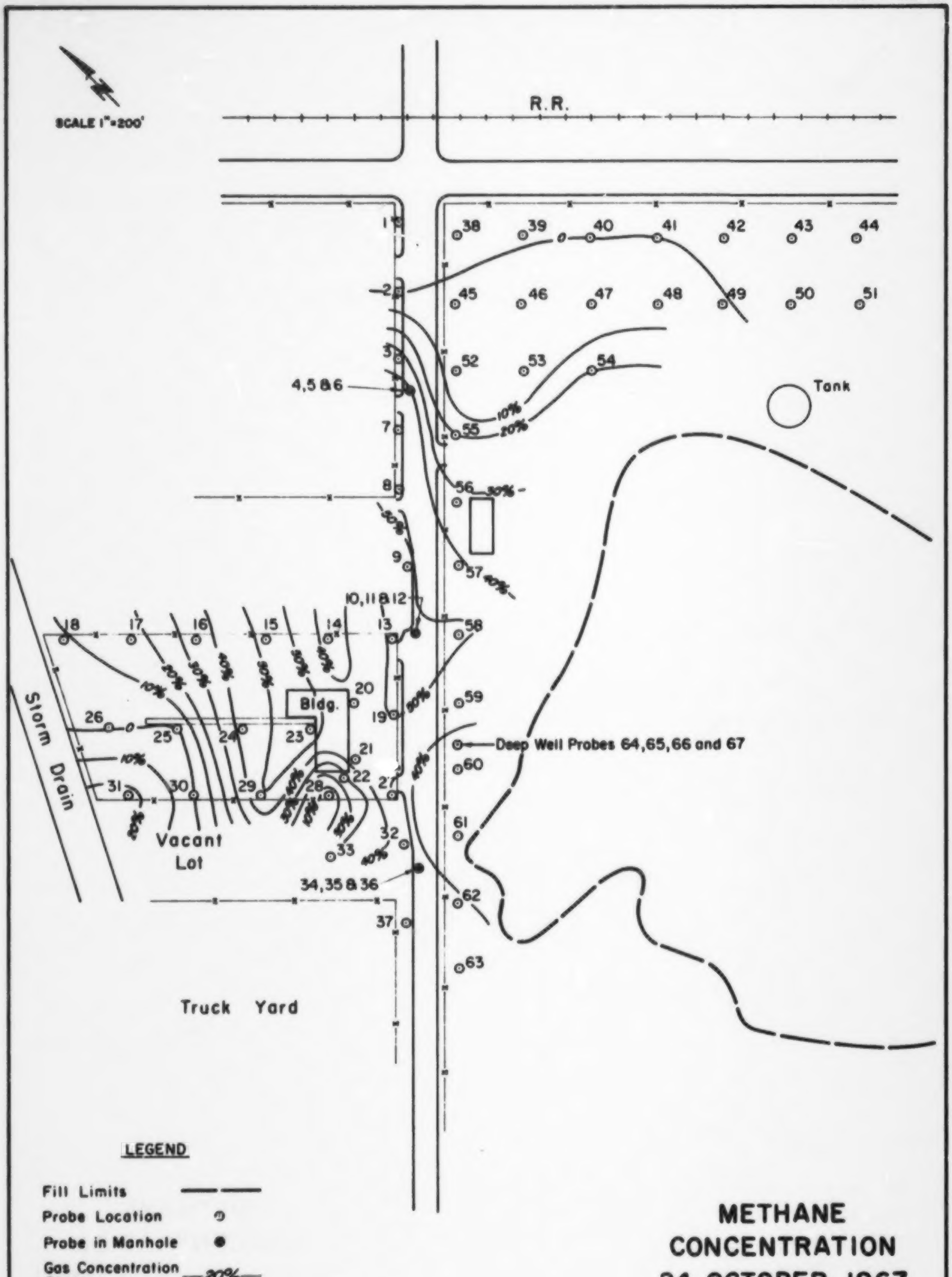
FIGURE III-12


SCALE 1"=200'
R.R.
Tank
Bldg.
Storm Drain
Vacant Lot
Truck Yard
Deep Well Probes 64, 65, 66 and 67
4,5 & 6
10,11 & 12
34,35 & 36
1
2
3
7
8
9
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
0
10%
20%
30%
40%
LEGEND
Fill Limits
Probe Location
Probe in Manhole
Gas Concentration Contour
20%

METHANE
CONCENTRATION
26 JULY, 9 AUGUST 1967
SITE NO. 1

ENGINEERING-SCIENCE, INC.

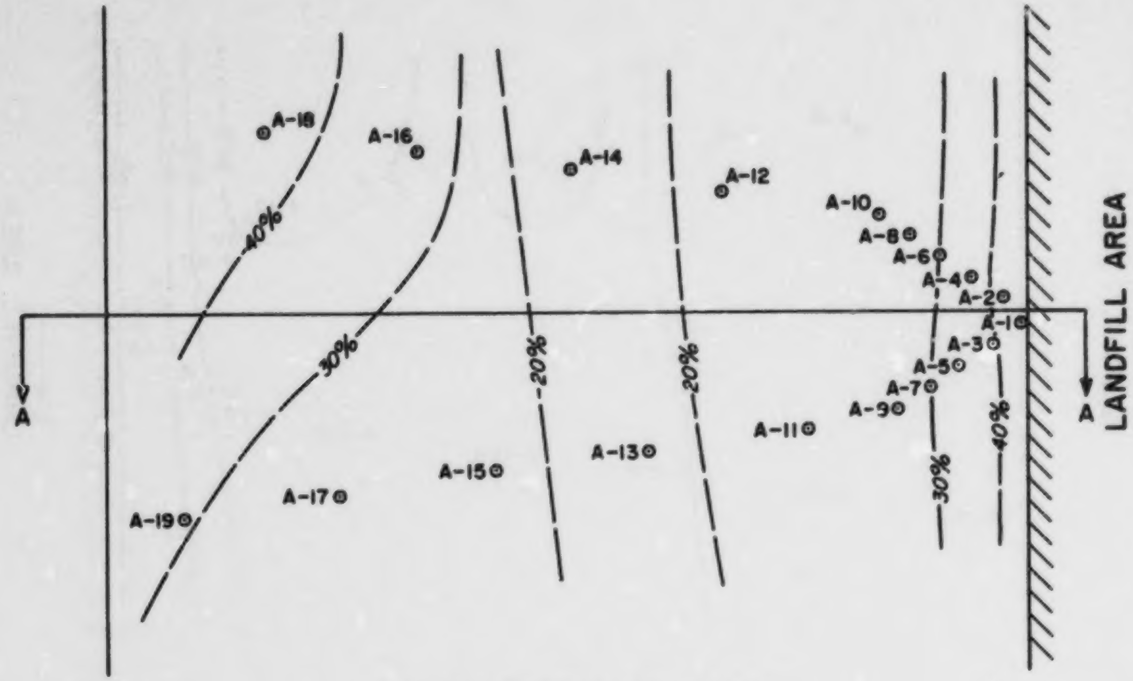
FIGURE III-13


N
SCALE 1" = 200'
R.R.
Tank
Storm Drain
Vacant Lot
Truck Yard
Bldg.
4,5 & 6
10,11 & 12
34,35 & 36
Deep Well Probes 64,65,66 and 67
0
10%
20%
30%
40%
1
2
3
7
8
9
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
37
38
39
40
41
42
43
44
45
46
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
LEGEND
Fill Limits
Probe Location
Probe in Manhole
Gas Concentration Contour
20%

METHANE
CONCENTRATION
24 OCTOBER 1967
SITE NO. 1

ENGINEERING-SCIENCE, INC.

FIGURE III-14


A-18
A-16
A-14
A-12
A-10
A-8
A-6
A-4
A-2
A-1
A-3
A-5
A-7
A-9
A-11
A-13
A-15
A-17
A-19
40%
30%
20%
20%
30%
40%
A
A
LANDFILL AREA

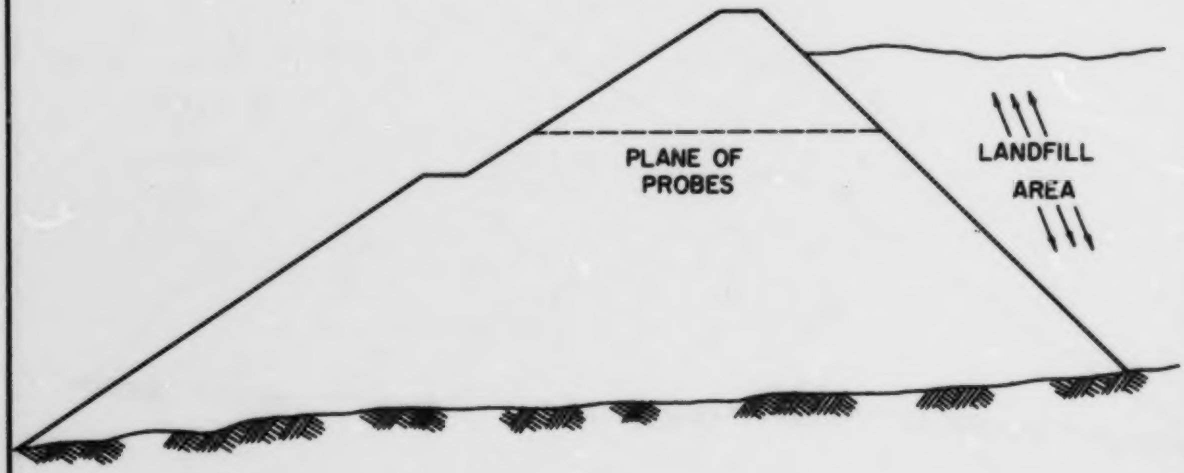
LEGEND

PROBE LOCATION ⊙

GAS CONCENTRATION CONTOUR —20%—

PROBE LOCATION PLAN

SCALE 1"= 20'


PLANE OF PROBES
LANDFILL AREA

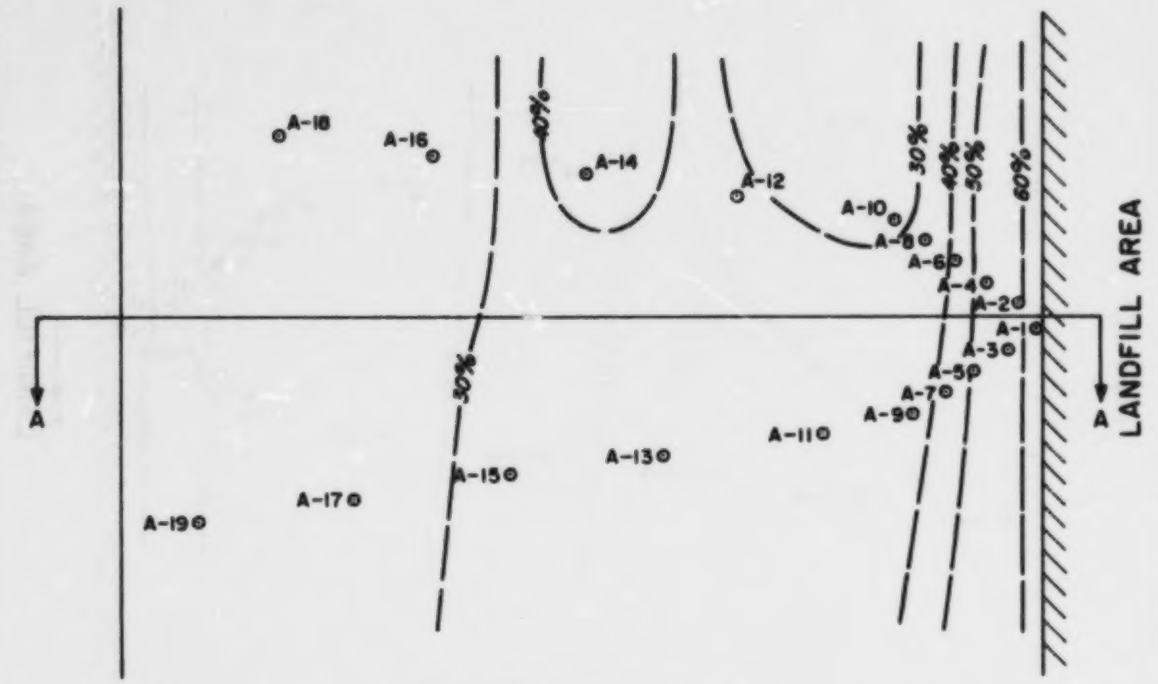
SECTION A-A

NOT TO SCALE

CARBON DIOXIDE
CONCENTRATION
16 MAY 1967
SITE NO. 2-A

ENGINEERING - SCIENCE, INC.

FIGURE III-15


A-18
A-16
40%
A-14
A-12
30%
40%
50%
60%
A-10
A-8
A-6
A-4
A-2
A-1
A-3
A-5
A-7
A-9
A-11
A-13
A-15
A-17
A-19
30%
A
A
LANDFILL AREA

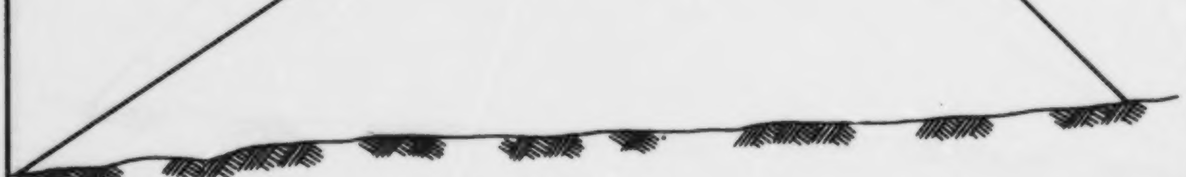
LEGEND

PROBE LOCATION ⊙

GAS CONCENTRATION CONTOUR —20%—

PROBE LOCATION PLAN

SCALE 1" = 20'

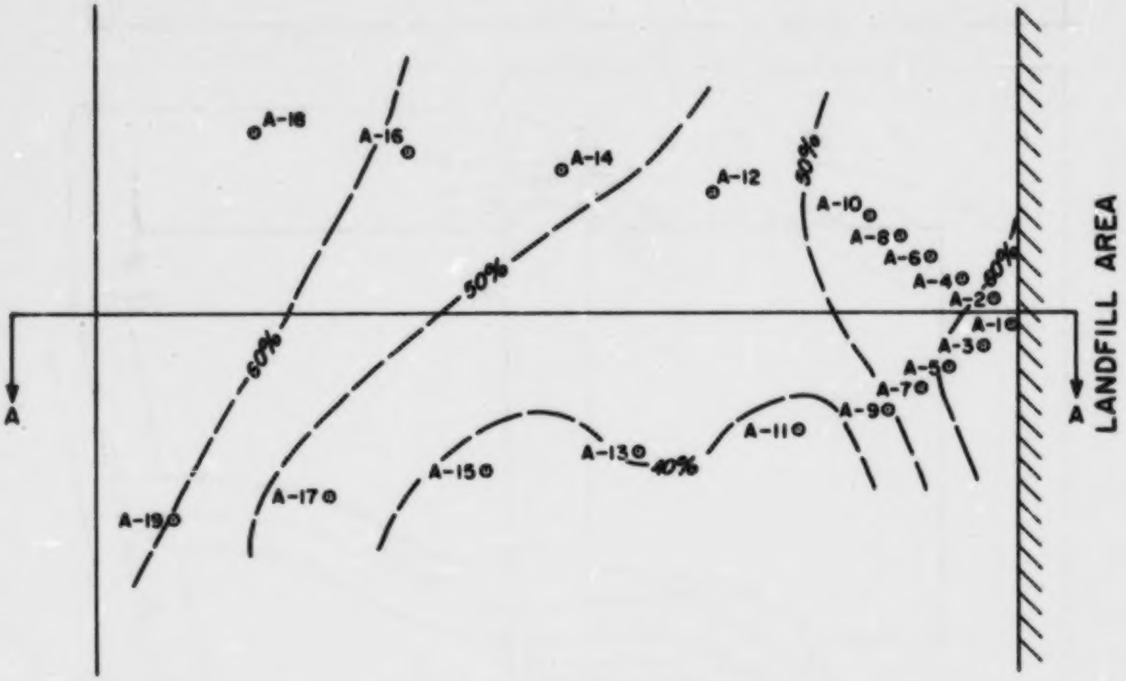

PLANE OF PROBES
LANDFILL AREA

SECTION A-A

NOT TO SCALE

CARBON DIOXIDE CONCENTRATION
7 JULY 1967
SITE NO. 2-A

ENGINEERING - SCIENCE, INC.


A-18
A-16
A-14
A-12
50%
A-10
A-8
A-6
A-4
80%
A-2
A-1
A-3
A-5
A-7
A-9
A-11
A-13
40%
A-15
A-17
A-19
60%
50%
A
A
LANDFILL AREA

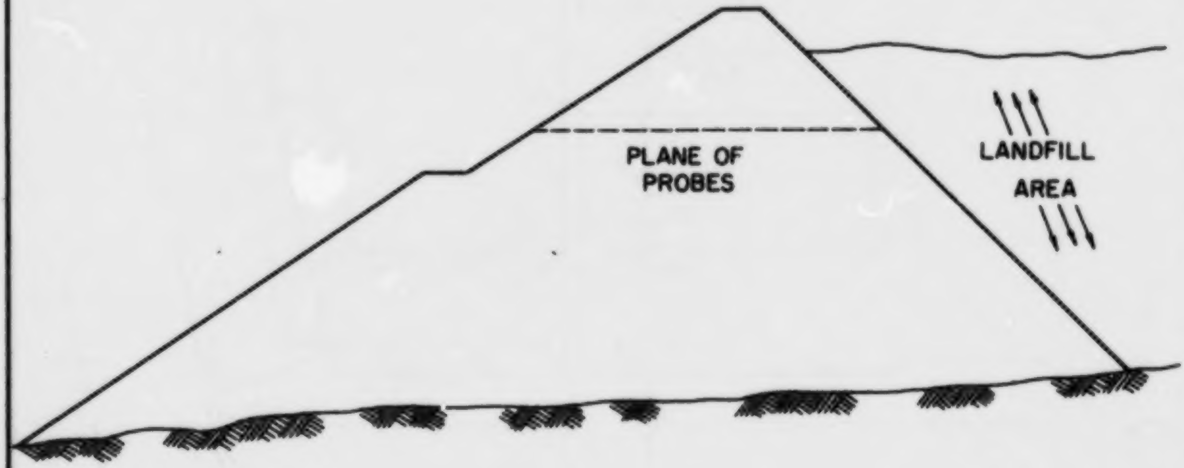
LEGEND

PROBE LOCATION ⊙

GAS CONCENTRATION CONTOUR —20%—

PROBE LOCATION PLAN

SCALE 1" = 20'


PLANE OF PROBES
LANDFILL AREA

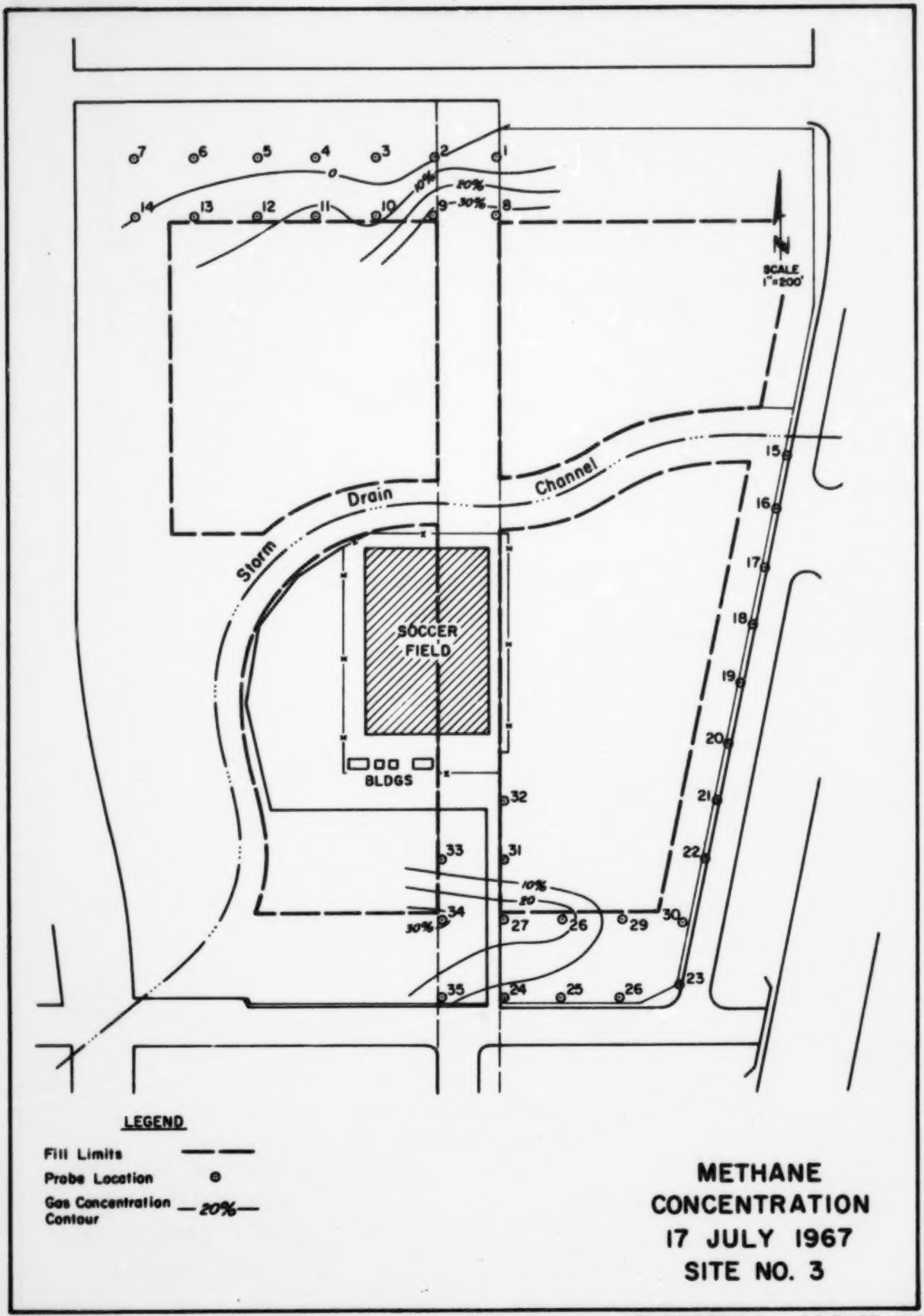
SECTION A-A

NOT TO SCALE

CARBON DIOXIDE CONCENTRATION 12 SEPTEMBER 1967 SITE NO. 2-A

ENGINEERING - SCIENCE, INC.

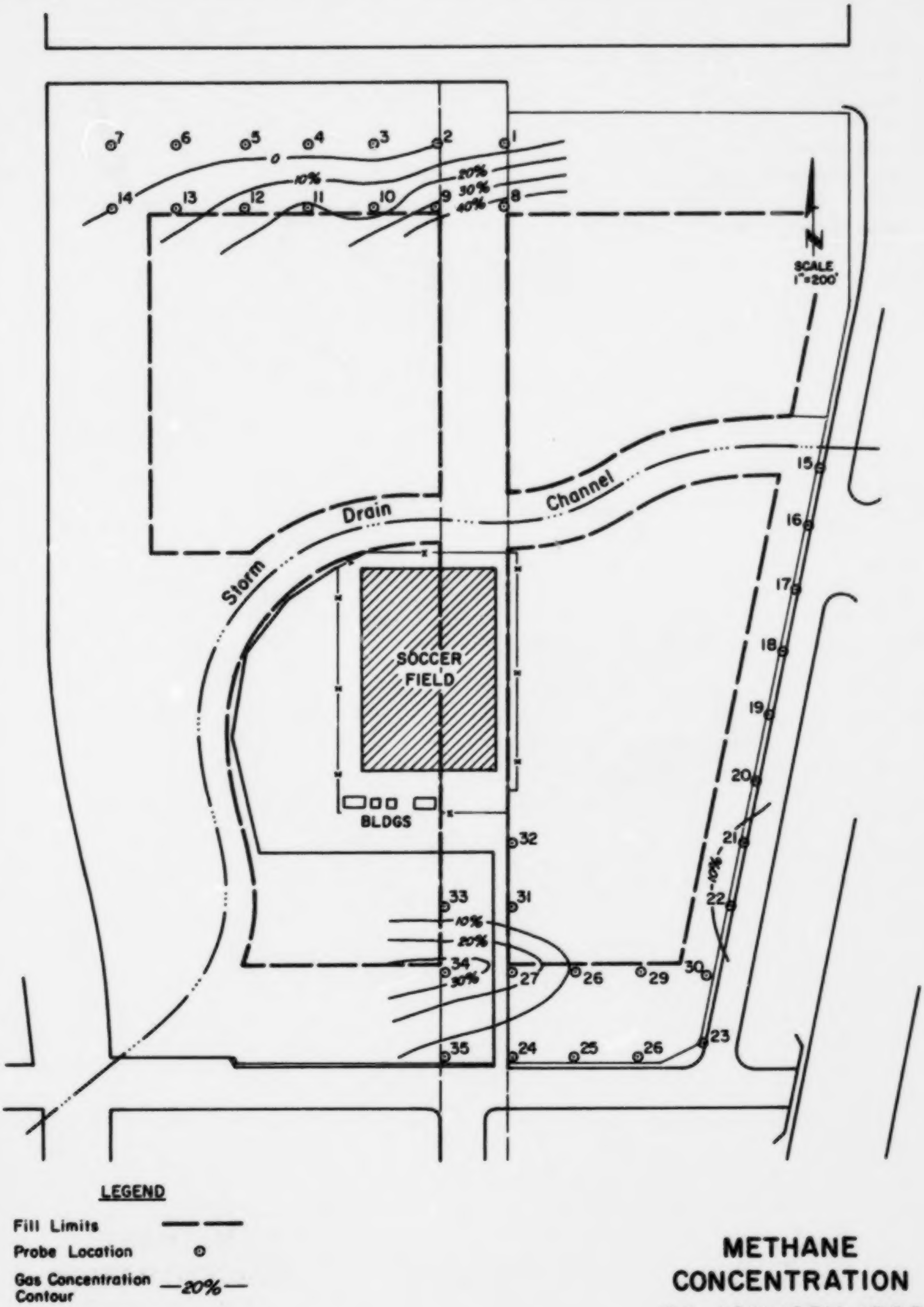
FIGURE III-17


1
2
3
4
5
6
7
8
9
10
11
12
13
14
0
10%
20%
30%
N
SCALE
1"=200'
Storm
Drain
Channel
15
16
17
18
19
20
21
22
23
SOCCER FIELD
BLDGS
32
33
31
10%
20
30%
34
27
26
29
30
35
24
25
26
LEGEND
Fill Limits
Probe Location
Gas Concentration Contour
20%

METHANE
CONCENTRATION
17 JULY 1967
SITE NO. 3

ENGINEERING, - SCIENCE, INC.

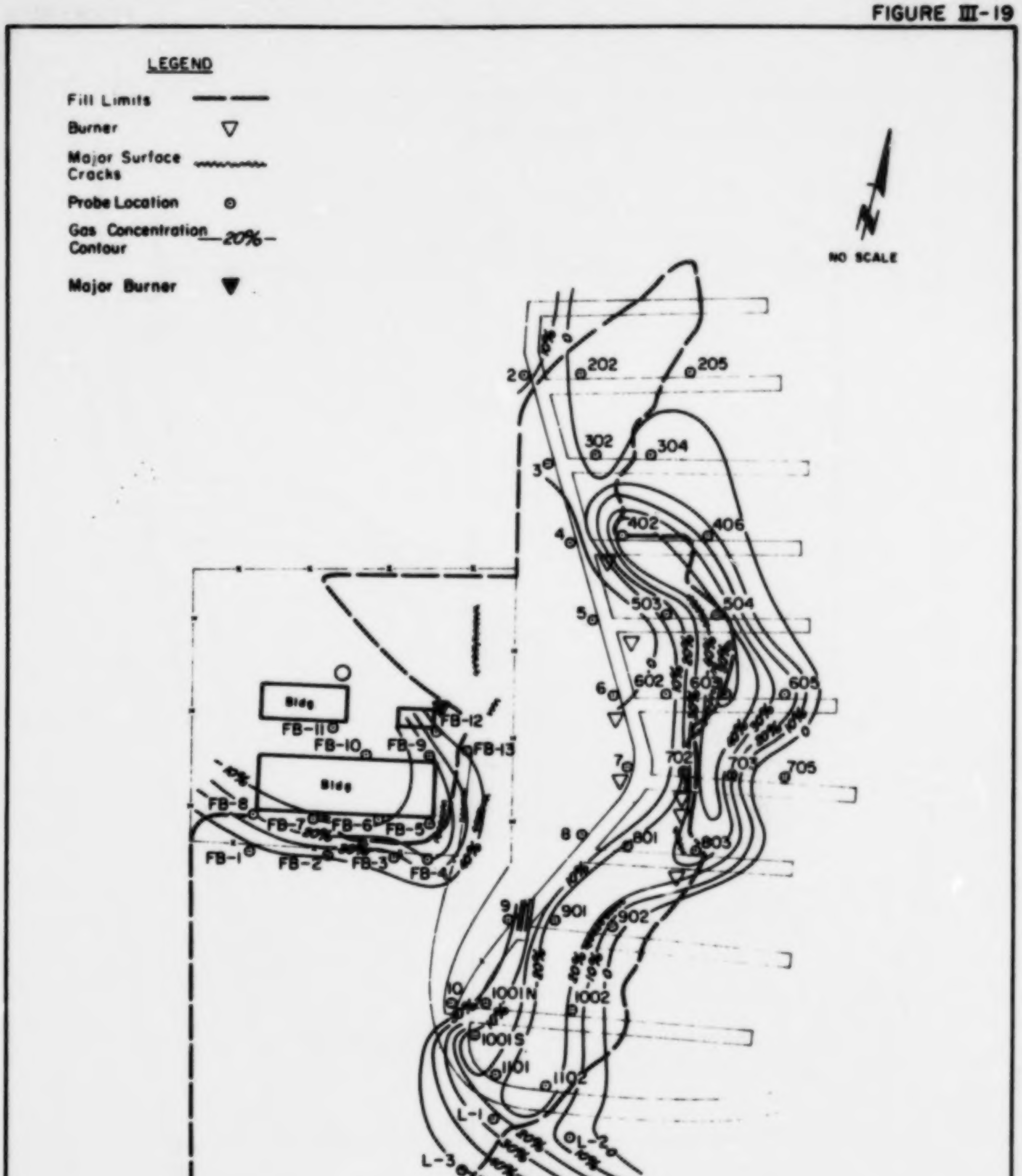
FIGURE III-18


1
2
3
4
5
6
7
8
9
10
11
12
13
14
0
10%
20%
30%
40%
N
SCALE
1"=200'
Storm Drain Channel
SOCCER FIELD
BLDGS
15
16
17
18
19
20
21
22
10%
23
24
25
26
26
27
29
30
31
32
33
34
35
10%
20%
30%
LEGEND
Fill Limits
Probe Location
Gas Concentration Contour
20%

METHANE CONCENTRATION
24 JANUARY 1968
SITE NO. 3

ENGINEERING, – SCIENCE, INC.

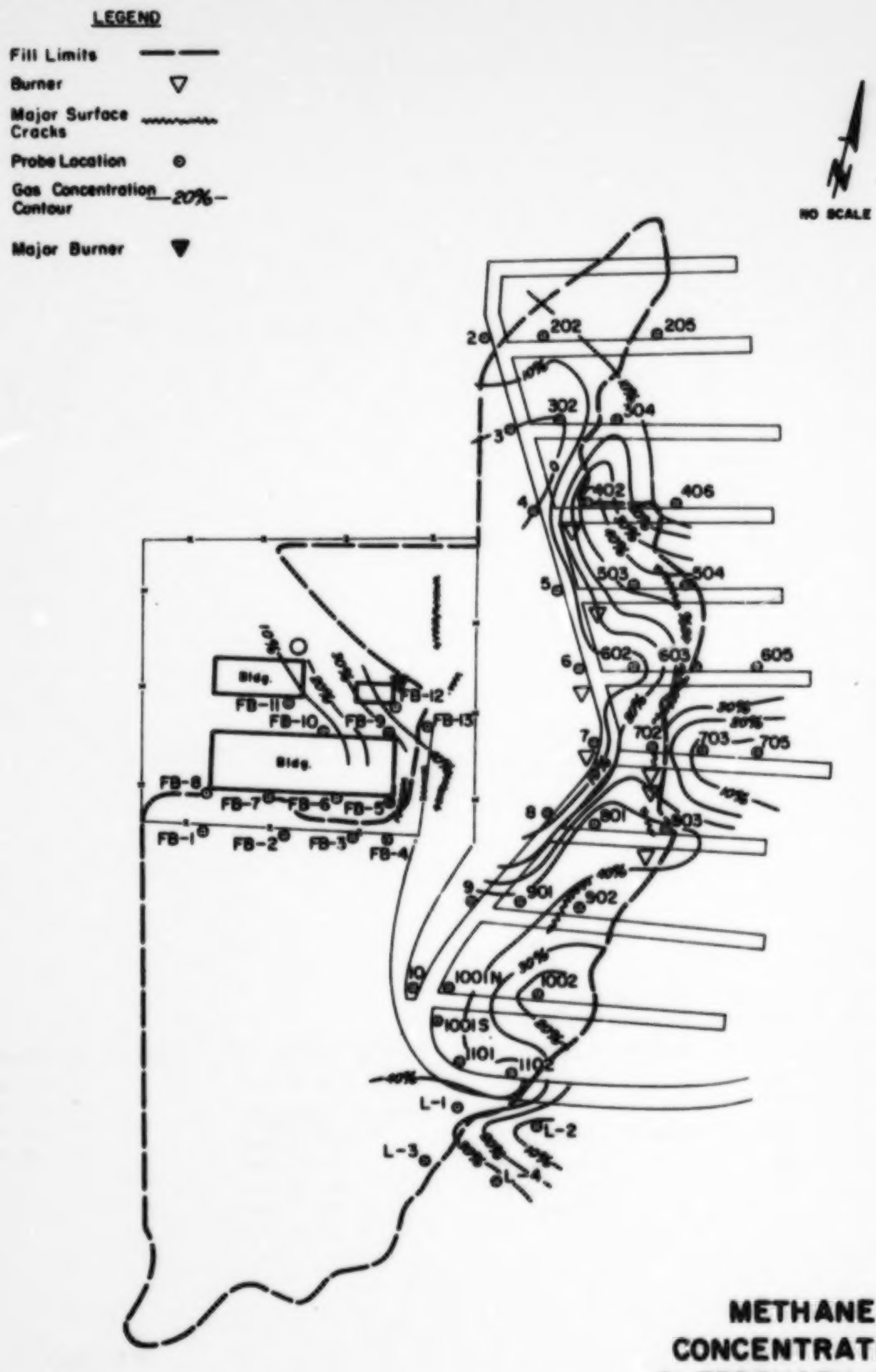
FIGURE III-19


LEGEND
Fill Limits
Burner ▽
Major Surface Cracks
Probe Location ⊙
Gas Concentration Contour —20%—
Major Burner ▼
NO SCALE
N
Bldg
Bldg
2
202
205
3
302
304
4
402
406
5
503
504
6
602
603
605
7
702
703
705
8
801
803
9
901
902
10
1001N
1001S
1002
1101
1102
L-1
L-2
L-3
L-4
FB-1
FB-2
FB-3
FB-4
FB-5
FB-6
FB-7
FB-8
FB-9
FB-10
FB-11
FB-12
FB-13
0
10%
20%
30%

METHANE
CONCENTRATION
7 JULY 1967
SITE NO. 4

ENGINEERING - SCIENCE, INC.

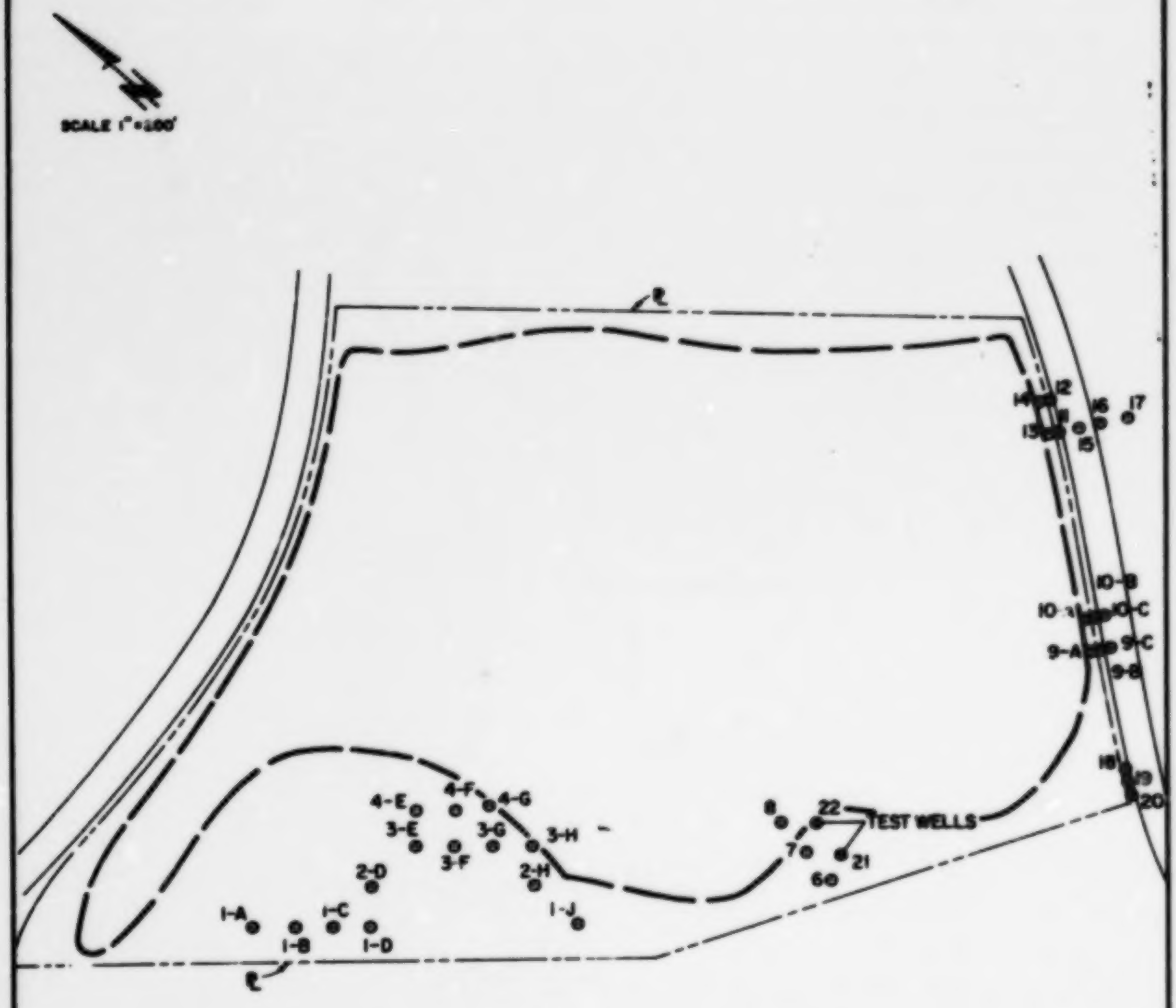
FIGURE III-20


LEGEND
Fill Limits
Burner ▽
Major Surface Cracks
Probe Location ⊙
Gas Concentration Contour —20%—
Major Burner ▼
N
NO SCALE
2
202
205
10%
302
304
3
4
402
406
5
503
504
6
602
603
605
7
702
703
705
30%
20%
10%
8
801
803
9
901
902
10
1001N
1002
1001S
1101
1102
40%
L-1
L-2
L-3
L-4
Bldg.
FB-1
FB-2
FB-3
FB-4
FB-5
FB-6
FB-7
FB-8
FB-9
FB-10
FB-11
FB-12
FB-13

METHANE
CONCENTRATION
21 FEBRUARY 1968
SITE NO. 4

ENGINEERING - SCIENCE, INC.

FIGURE III-21


SCALE 1" = 100'
℄
4-E
4-F
4-G
3-E
3-G
3-H
3-F
2-D
2-H
1-A
1-B
1-C
1-D
1-J
8
22
TEST WELLS
7
21
6
14
12
11
13
15
16
17
10-B
10-A
10-C
9-A
9-C
9-B
18
19
20
℄

NOTES:

Probes 13 thru 20 installed by Public Agency.
Probes 21 and 22 installed by ES previous study.

Probe 13 – 5 Probes
- A - 100' deep
- B - 75' deep
- C - 50' deep
- D - 25' deep
- E - 10' deep

Probe 14 – 1 Probe
15' deep in trench.

Probe 15 – 5 Probes
Could find only one, assumed 10' deep.

Probe 16 – 1 Probe
15' deep

Probe 17 – 4 Probes
- B - 75' deep
- C - 50' deep
- D - 25' deep
- E - 10' deep

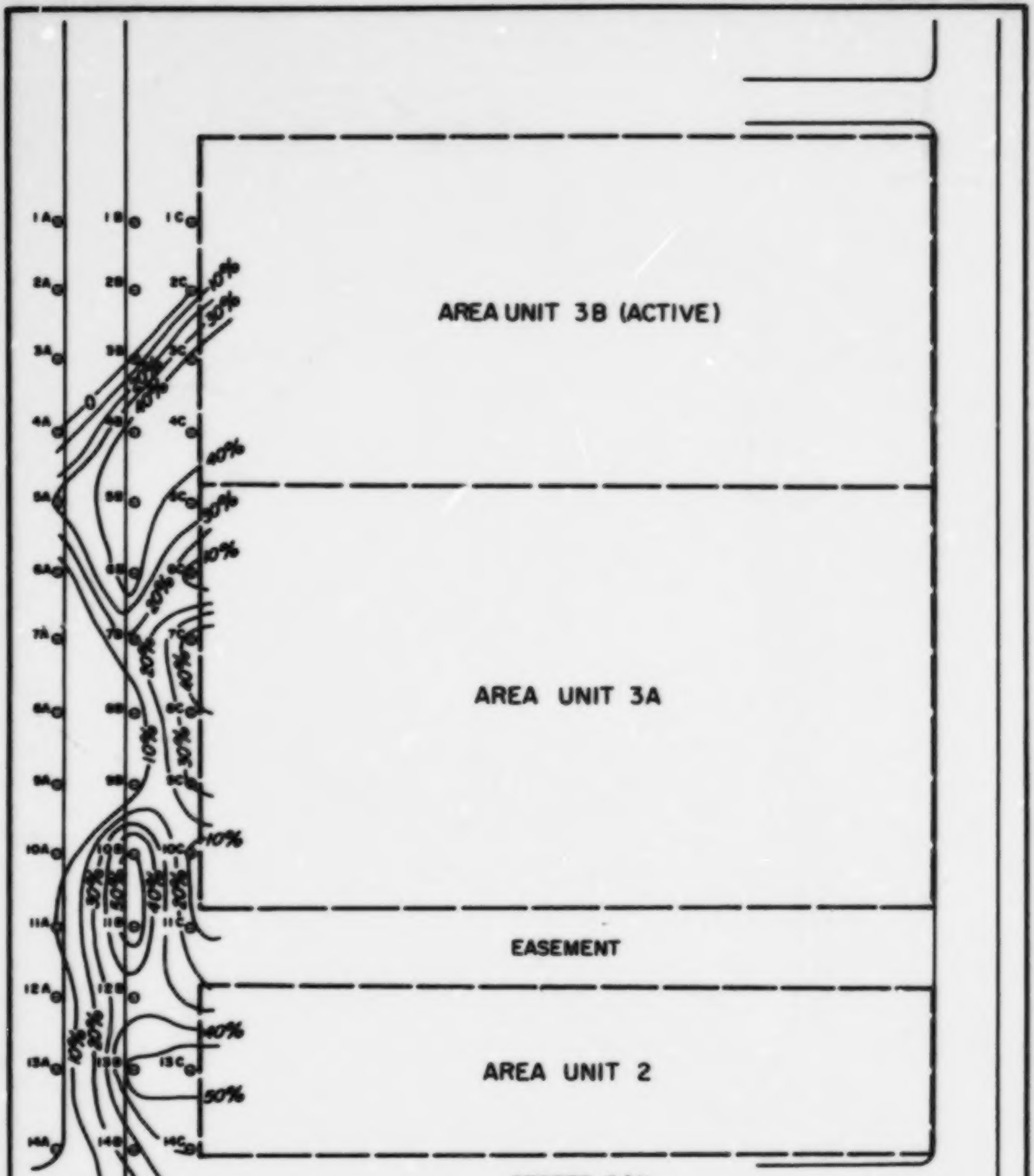
Probe 21 – 4 Probes
- A - 100' deep
- B - 75' deep
- C - 50' deep
- D - 25' deep

LEGEND

Fill Limits — —
Probe Location ○
Probe in Deep Well ●

PROBE
LOCATION
SITE NO. 5

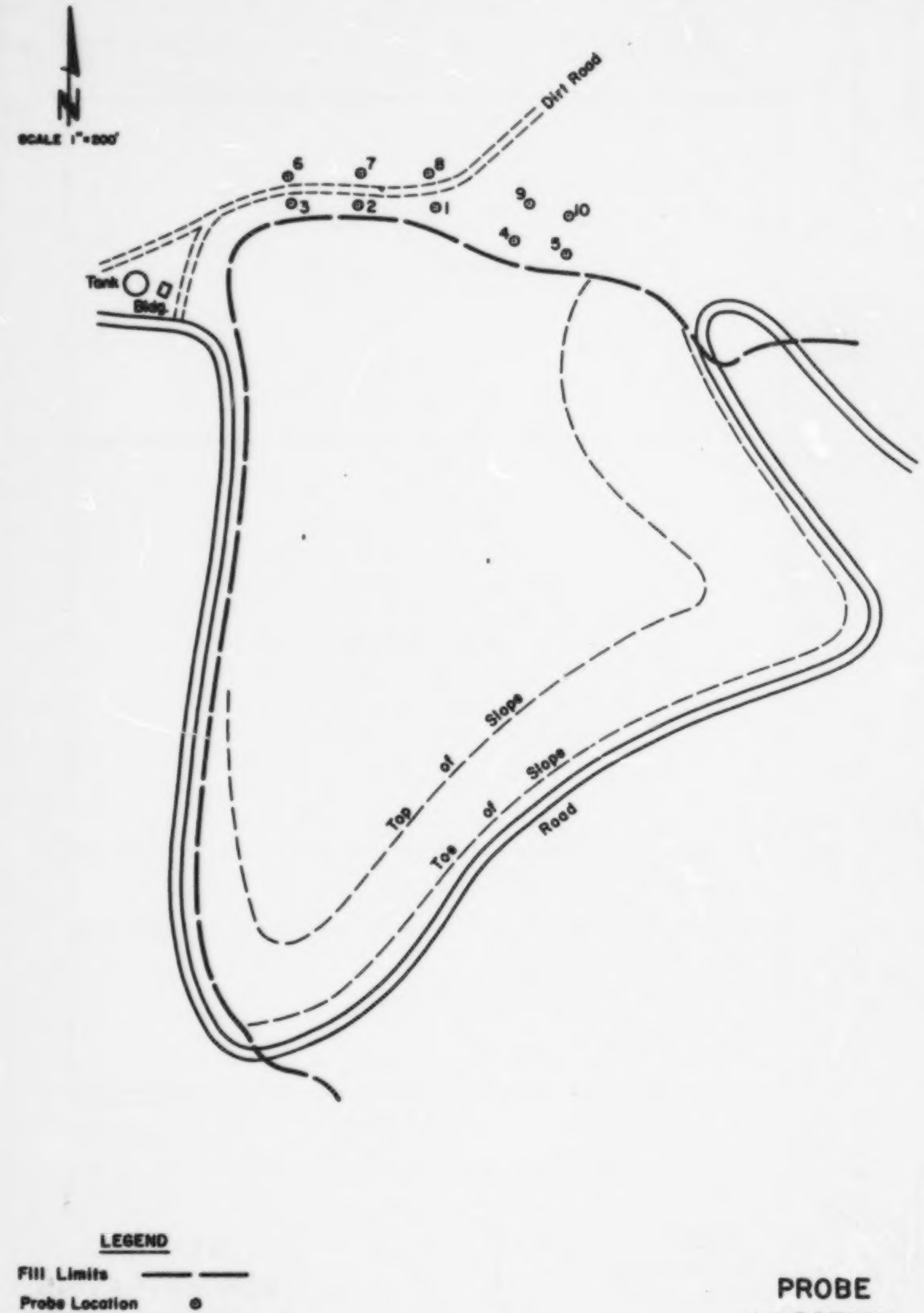
FIGURE III-22


AREA UNIT 3B (ACTIVE)
AREA UNIT 3A
EASEMENT
AREA UNIT 2
STREET R/W
1A 1B 1C
2A 2B 2C
3A 3B 3C
4A 4B 4C
5A 5B 5C
6A 6B 6C
7A 7B 7C
8A 8B 8C
9A 9B 9C
10A 10B 10C
11A 11B 11C
12A 12B
13A 13B 13C
14A 14B 14C
15A 15B 15C
16A 16B 16C
0
10%
20%
30%
40%
50%
LEGEND
Fill Limits
Probe Location
Gas Concentration Contour
20%
N
SCALE 1"=200'

METHANE CONCENTRATION
8 FEBRUARY 1968
SITE NO. 6

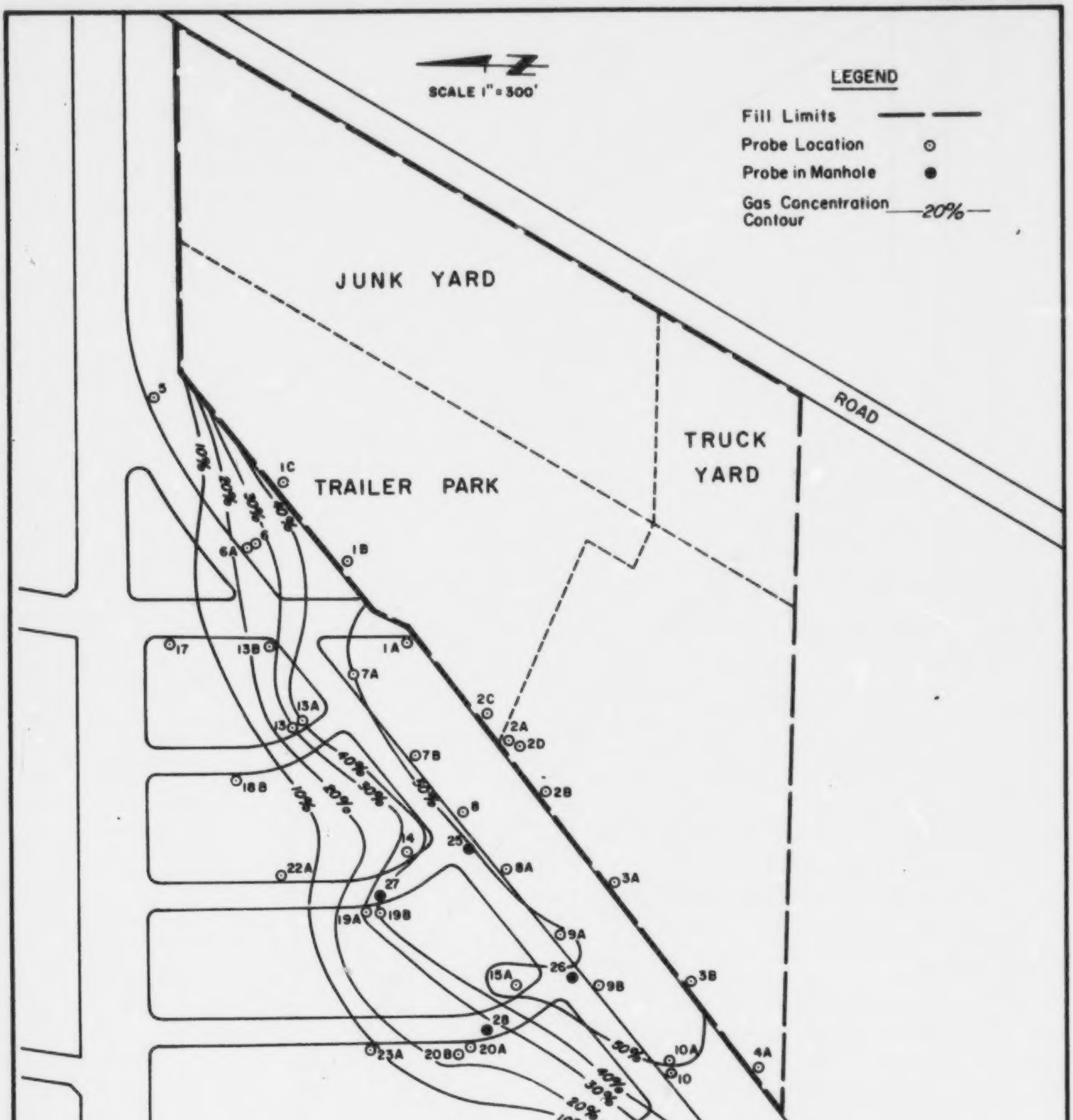
ENGINEERING - SCIENCE, INC.

FIGURE III-23


N
SCALE 1"=200'
Dirt Road
6
7
8
3
2
1
9
10
4
5
Tank
Bldg.
Top of Slope
Toe of Slope
Road
LEGEND
Fill Limits
Probe Location

PROBE
LOCATION
SITE NO. 7

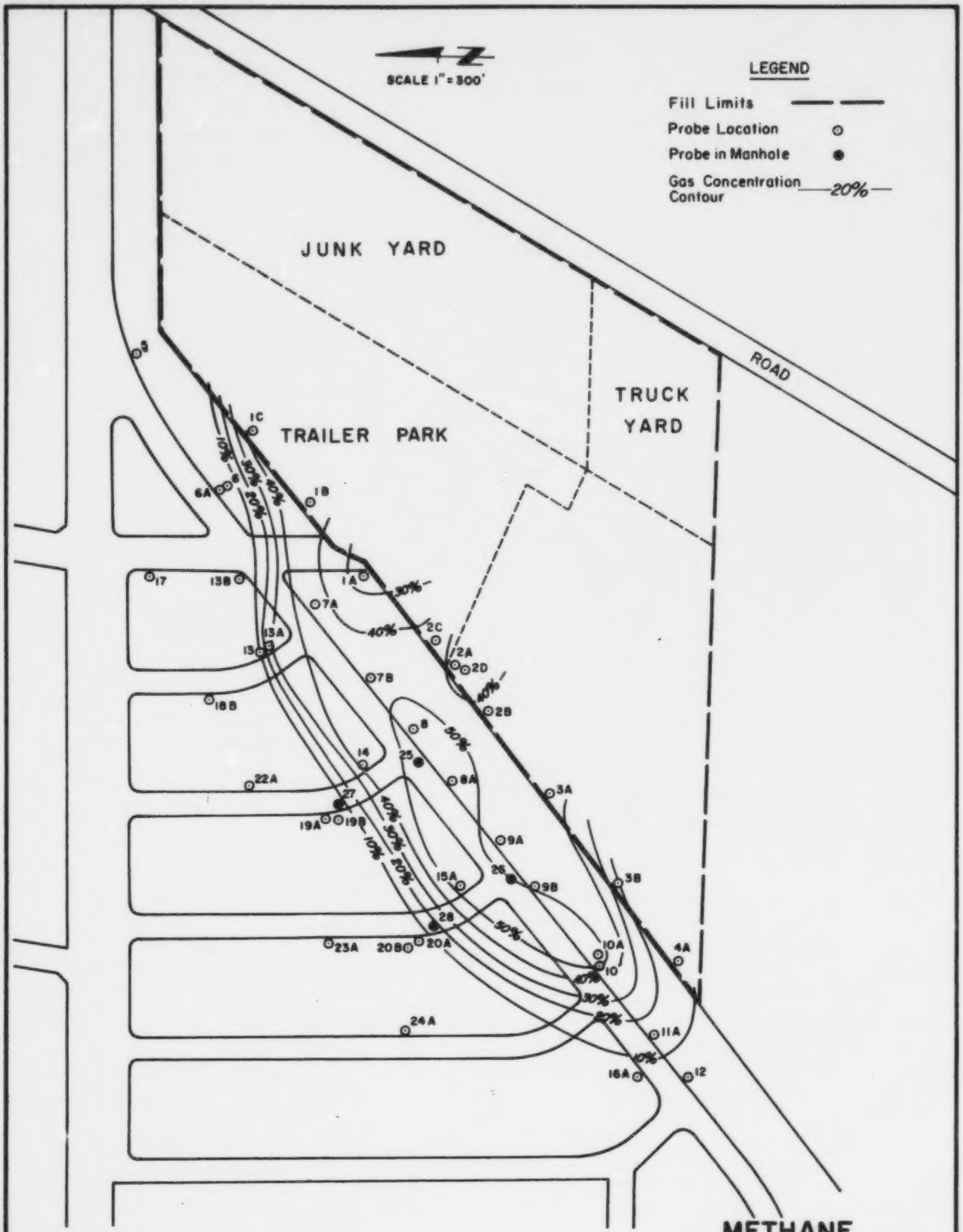
FIGURE III-24


N
SCALE 1" = 300'
LEGEND
Fill Limits
Probe Location ⊙
Probe in Manhole ●
Gas Concentration Contour 20%
JUNK YARD
TRUCK YARD
TRAILER PARK
ROAD
5
1C
1B
1A
6A
6
17
13B
13A
13
7A
7B
2C
2A
2D
2B
18B
8
25
8A
14
22A
27
19A
19B
3A
9A
15A
26
9B
3B
28
23A
20B
20A
10A
10
4A
24A
11A
16A
12
10%
20%
30%
40%
50%

METHANE CONCENTRATION
9 MAY 1967
SITE NO. 8

ENGINEERING—SCIENCE, INC.

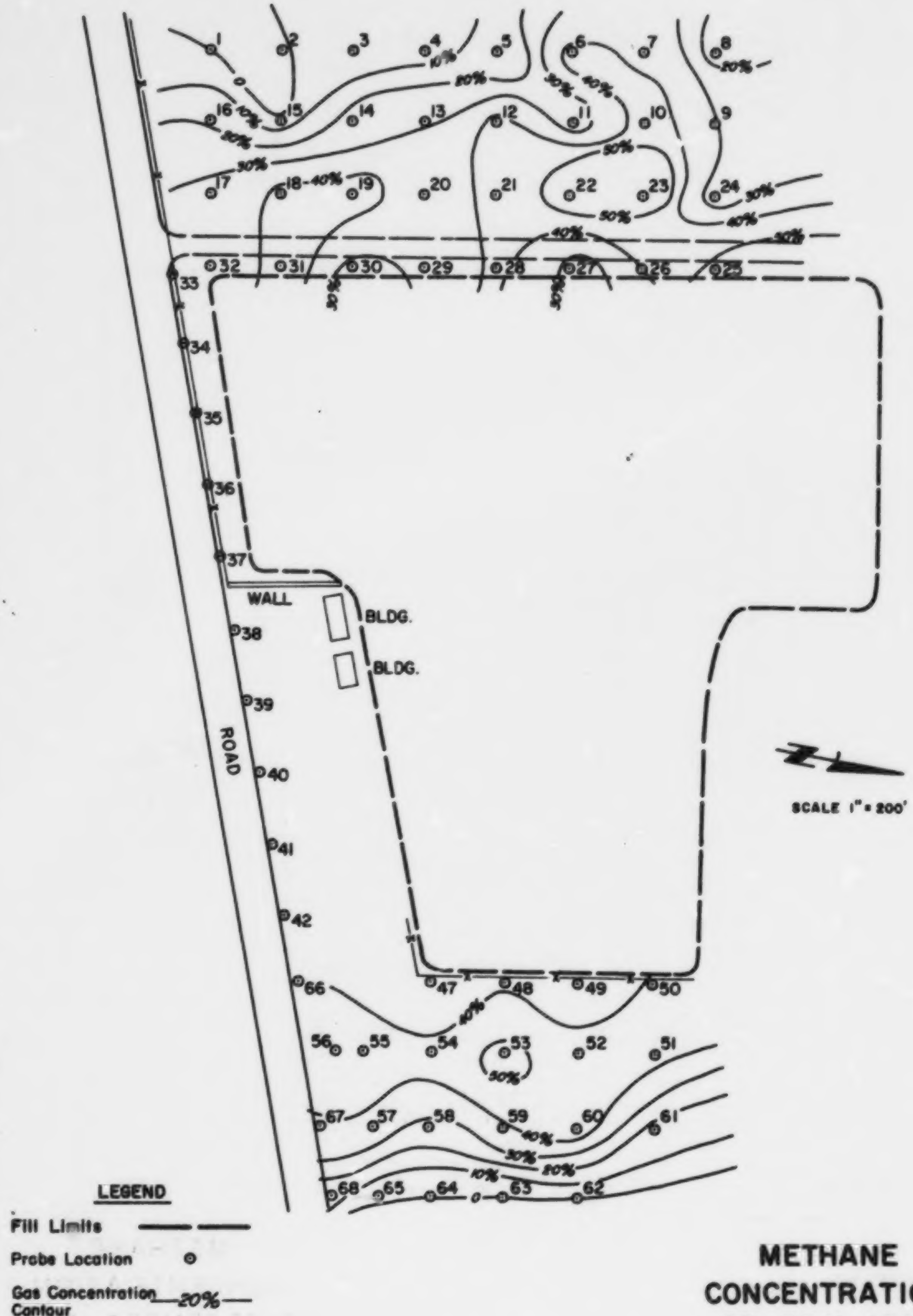
FIGURE III-25


N
SCALE 1" = 300'
LEGEND
Fill Limits
Probe Location
Probe in Manhole
Gas Concentration Contour
20%
JUNK YARD
TRUCK YARD
TRAILER PARK
ROAD
9
1C
6A
6
1B
17
13B
1A
30%
7A
2C
40%
13A
13
2A
2D
7B
40%
18B
2B
8
50%
25
14
8A
22A
27
3A
19A
19B
40%
30%
20%
10%
9A
26
9B
15A
3B
28
30%
23A
20B
20A
10A
10
4A
40%
30%
20%
24A
11A
10%
16A
12
10%
20%
30%
40%

METHANE CONCENTRATION 13 SEPTEMBER 1967 SITE NO. 8

ENGINEERING – SCIENCE, INC.

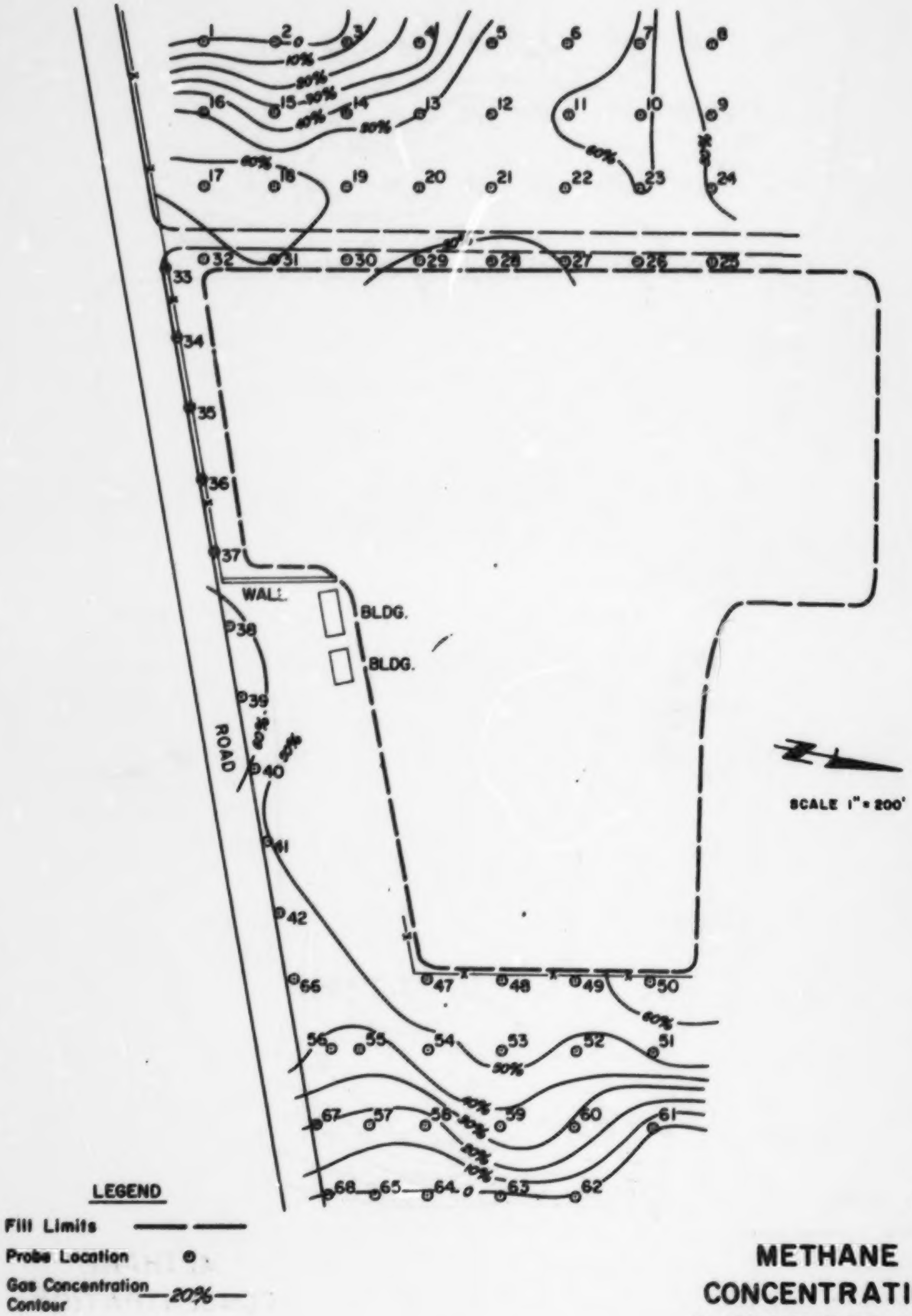
FIGURE III-26


1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18-40%
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
0
10%
20%
30%
40%
50%
WALL
BLDG.
BLDG.
ROAD
SCALE 1" = 200'
LEGEND
Fill Limits
Probe Location
Gas Concentration Contour
20%

METHANE CONCENTRATION 27 JULY 1967 SITE NO. 9

ENGINEERING - SCIENCE, INC.

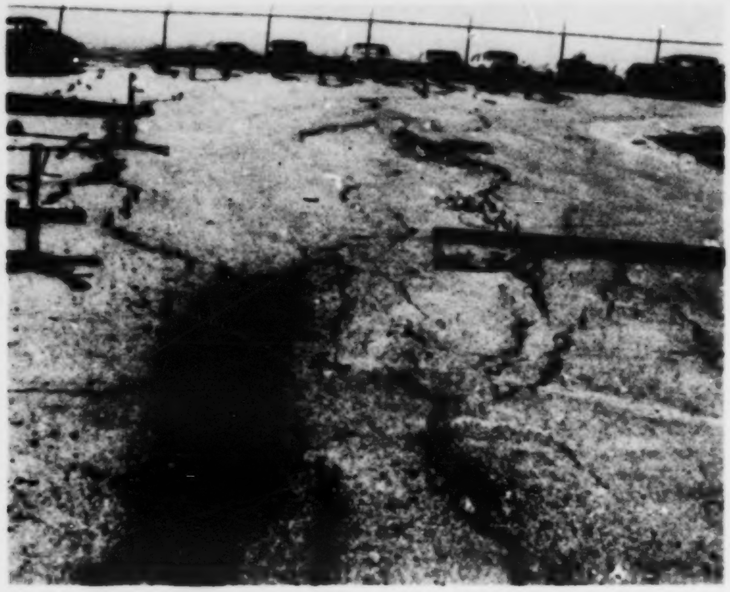
FIGURE III-27



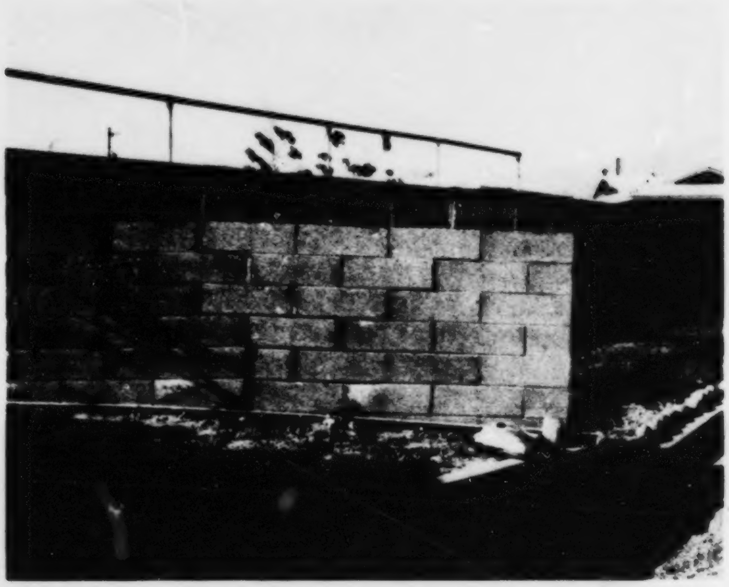
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
47
48
49
50
51
52
53
54
55
56
57
58
59
60
61
62
63
64
65
66
67
68
0
10%
20%
30%
40%
50%
60%
WALL
BLDG.
BLDG.
ROAD
N
SCALE 1" = 200'
LEGEND
Fill Limits
Probe Location
Gas Concentration Contour
20%

METHANE
CONCENTRATION
5 DECEMBER 1967
SITE NO. 9

ENGINEERING - SCIENCE, INC.

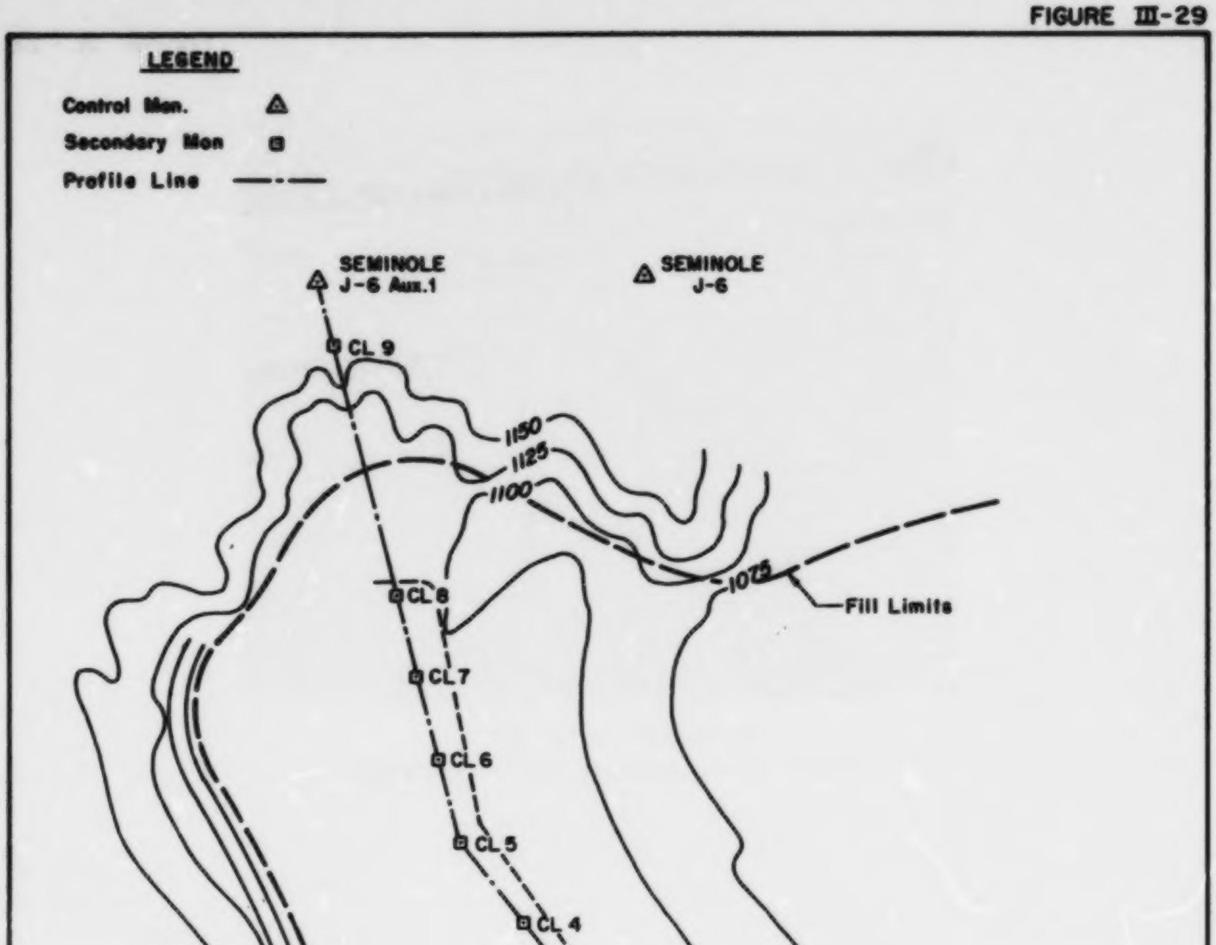


RESEARCH SITE NO. 4
Broken paving indicates unequal settlement.



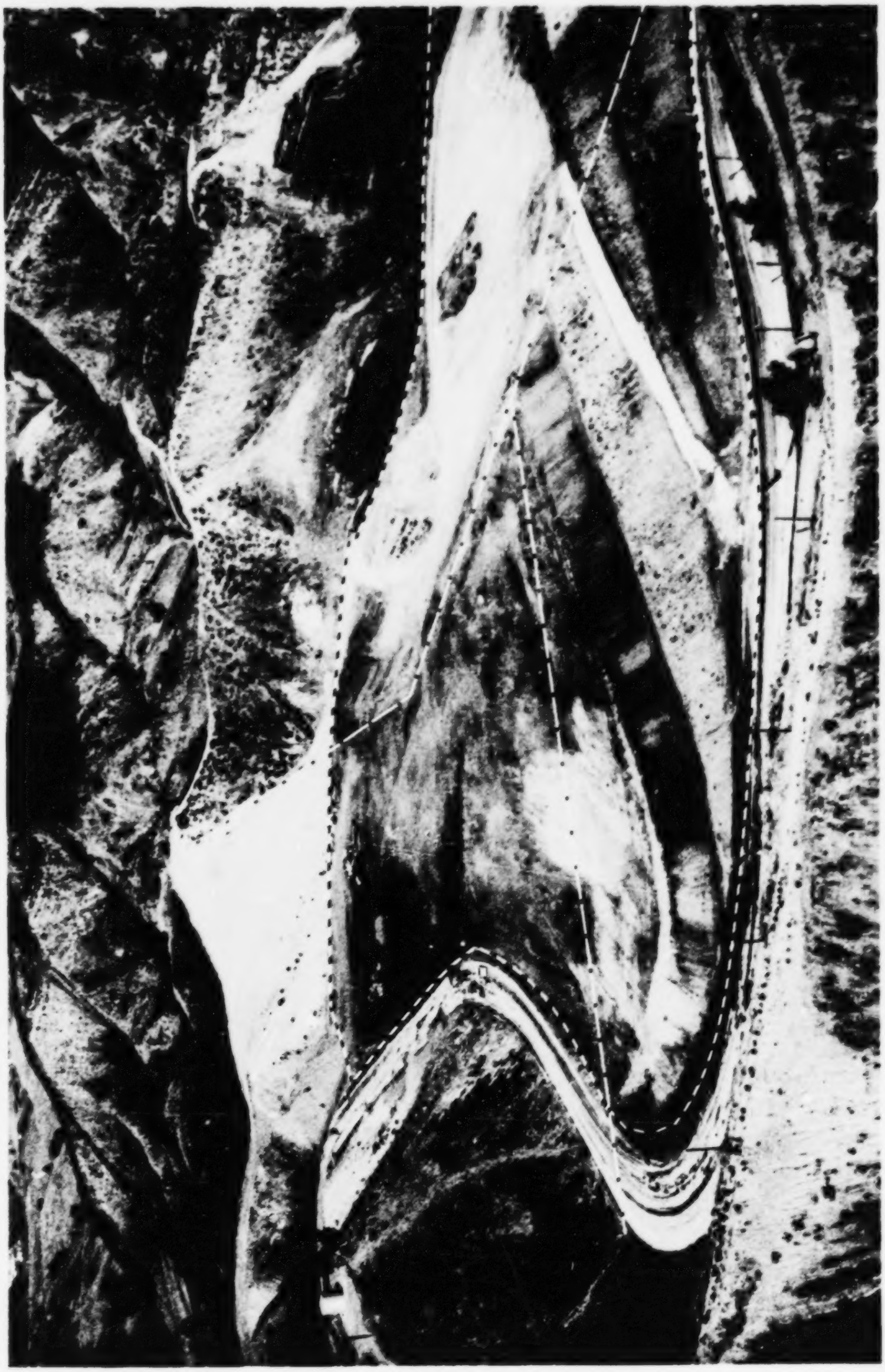
RESEARCH SITE NO. 8
Cracked wall shows result of settlement.

FIGURE III-29


LEGEND
Control Mon. △
Secondary Mon ▣
Profile Line —·—
SEMINOLE J-6 Aux.1
SEMINOLE J-6
CL 9
1150
1125
1100
1075
Fill Limits
CL 8
CL 7
CL 6
CL 5
CL 4
CL 3
CL 2
CL 10
CL 11
CL 12
CL 13
CL 14
Top of Slope
1150
1125
1100
1075
CL 1
SEMINOLE J-7
SEMINOLE J-7A

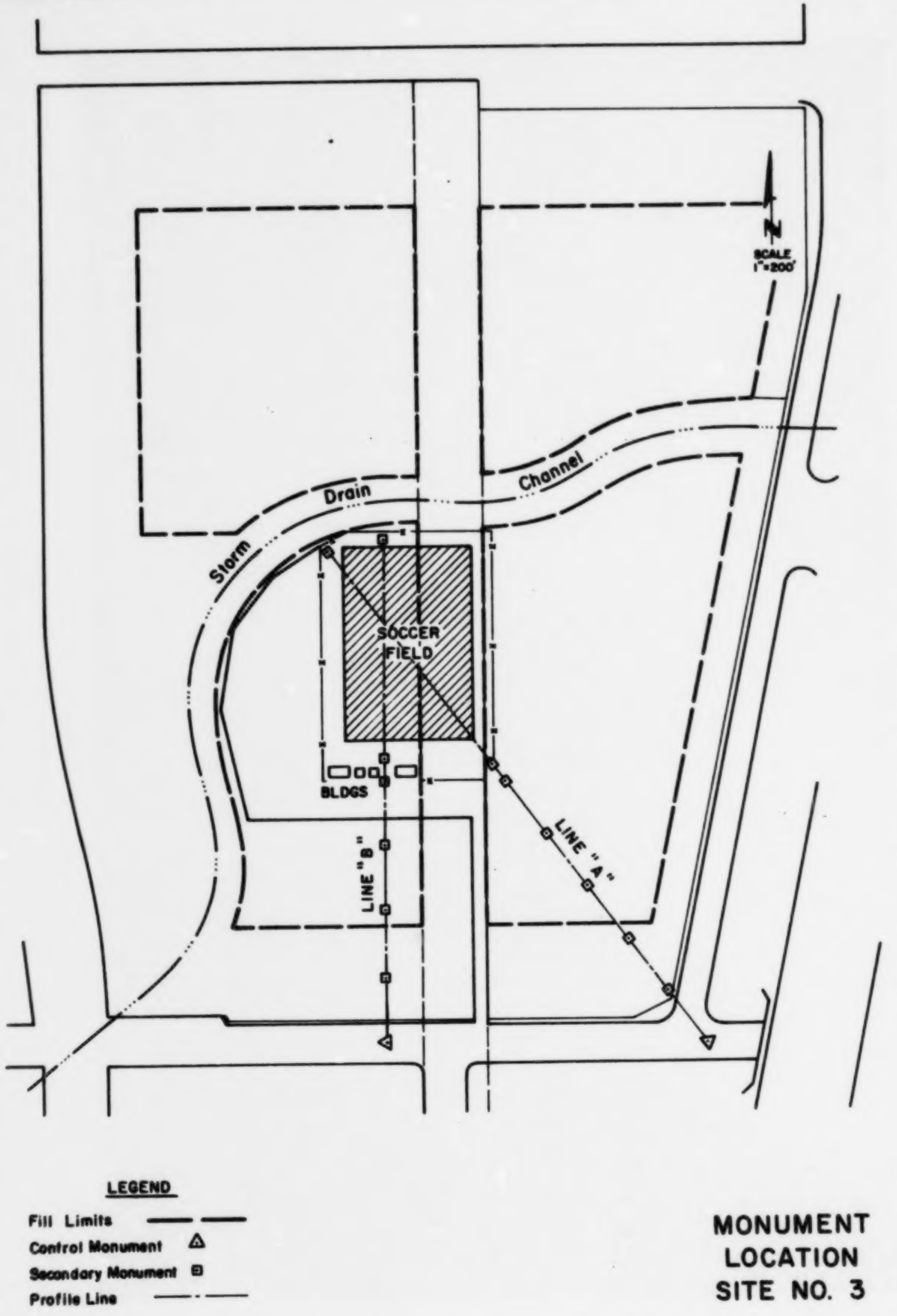
MONUMENT
LOCATION
SITE NO. 2-B

FIGURE III - 30



RESEARCH SITE NO. 2-B
Surveying monument system

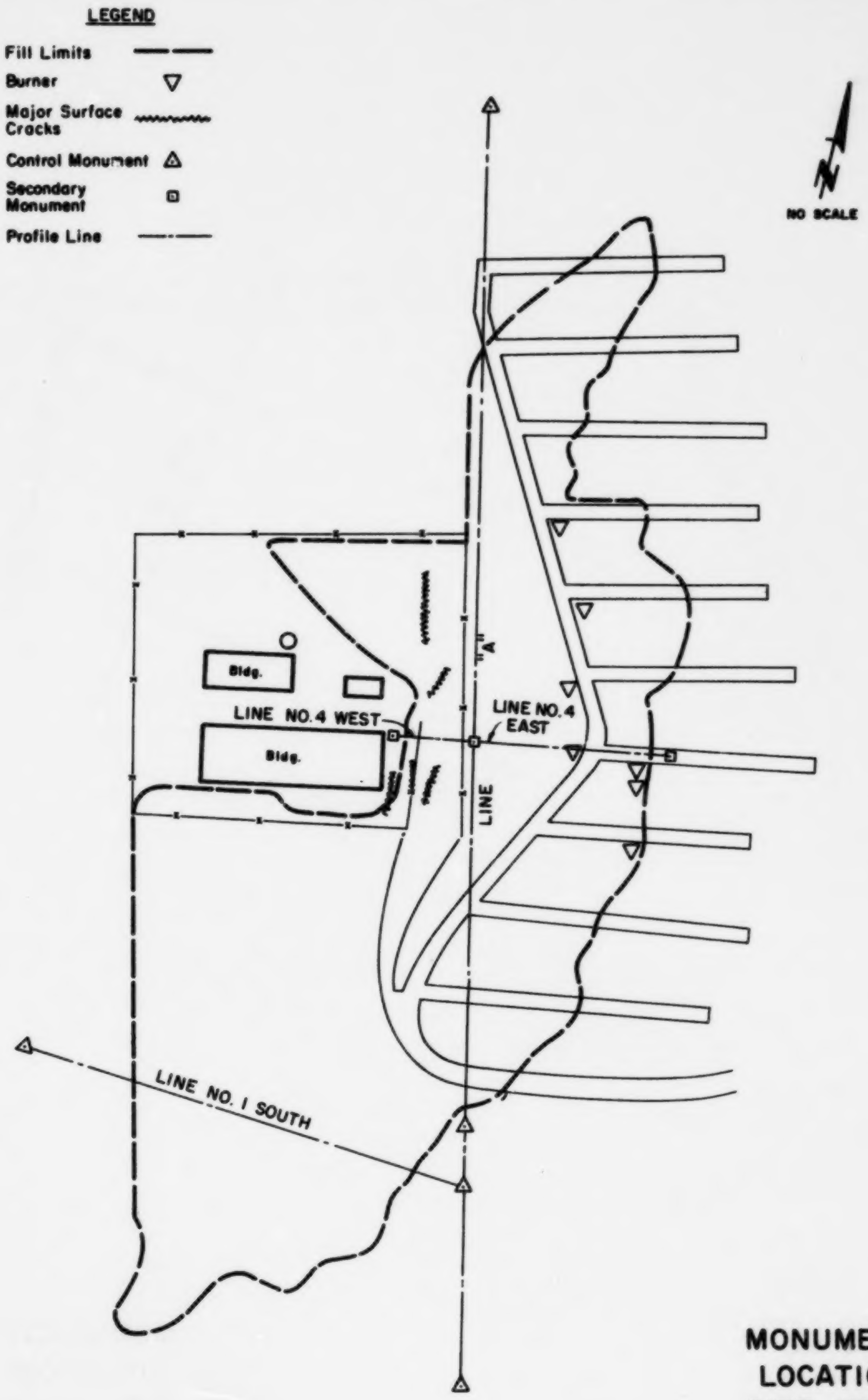
FIGURE III-31


N
SCALE
1"=200'
Storm Drain Channel
SOCCER FIELD
BLDGS
LINE "B"
LINE "A"
LEGEND
Fill Limits
Control Monument
Secondary Monument
Profile Line

MONUMENT
LOCATION
SITE NO. 3

ENGINEERING, - SCIENCE, INC.

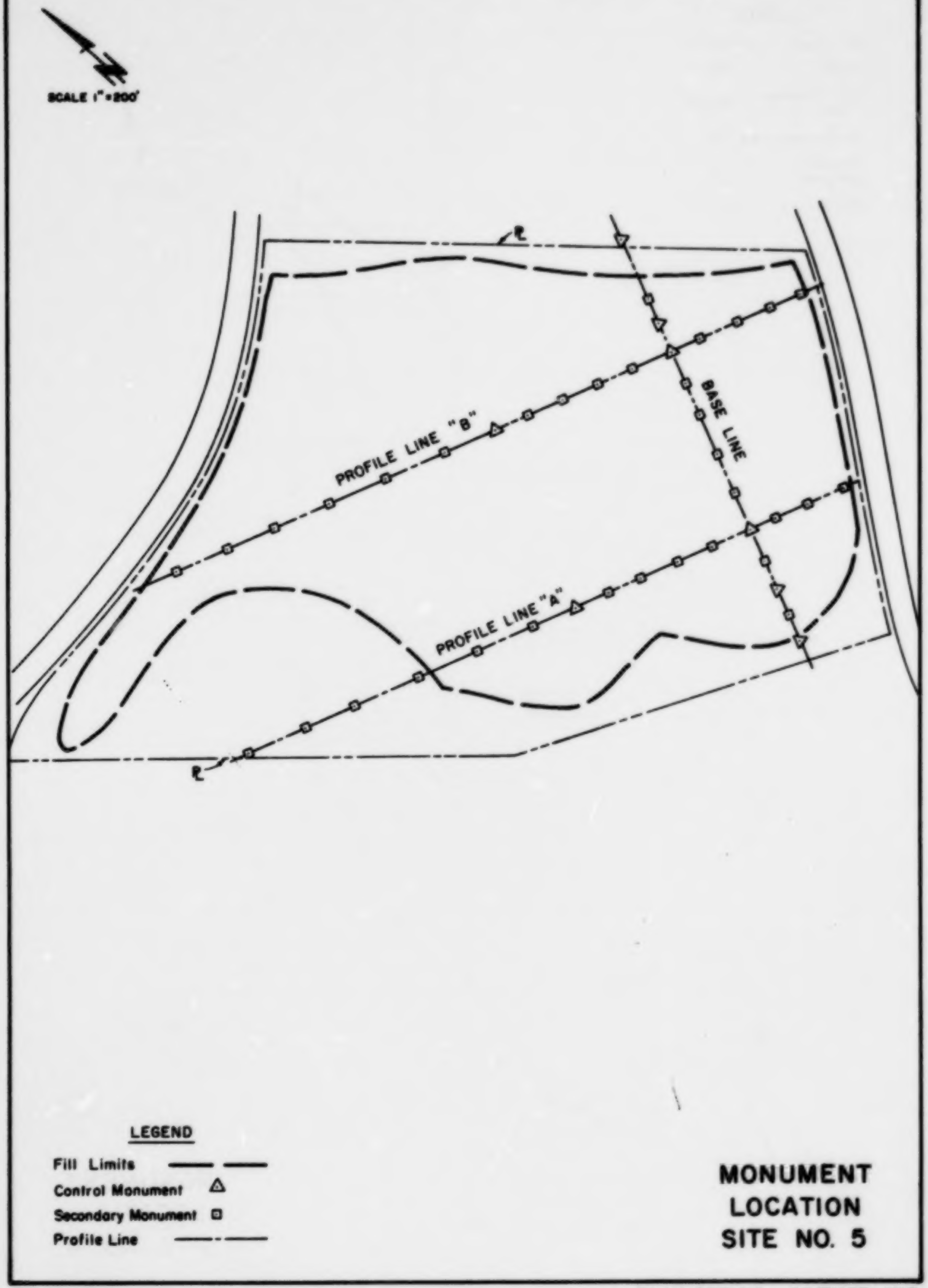
FIGURE III-32


LEGEND
Fill Limits
Burner
Major Surface Cracks
Control Monument
Secondary Monument
Profile Line
NO SCALE
Bldg.
Bldg.
LINE NO. 4 WEST
LINE NO. 4 EAST
LINE "A"
LINE NO. 1 SOUTH

MONUMENT
LOCATION
SITE NO. 4

ENGINEERING - SCIENCE, INC.

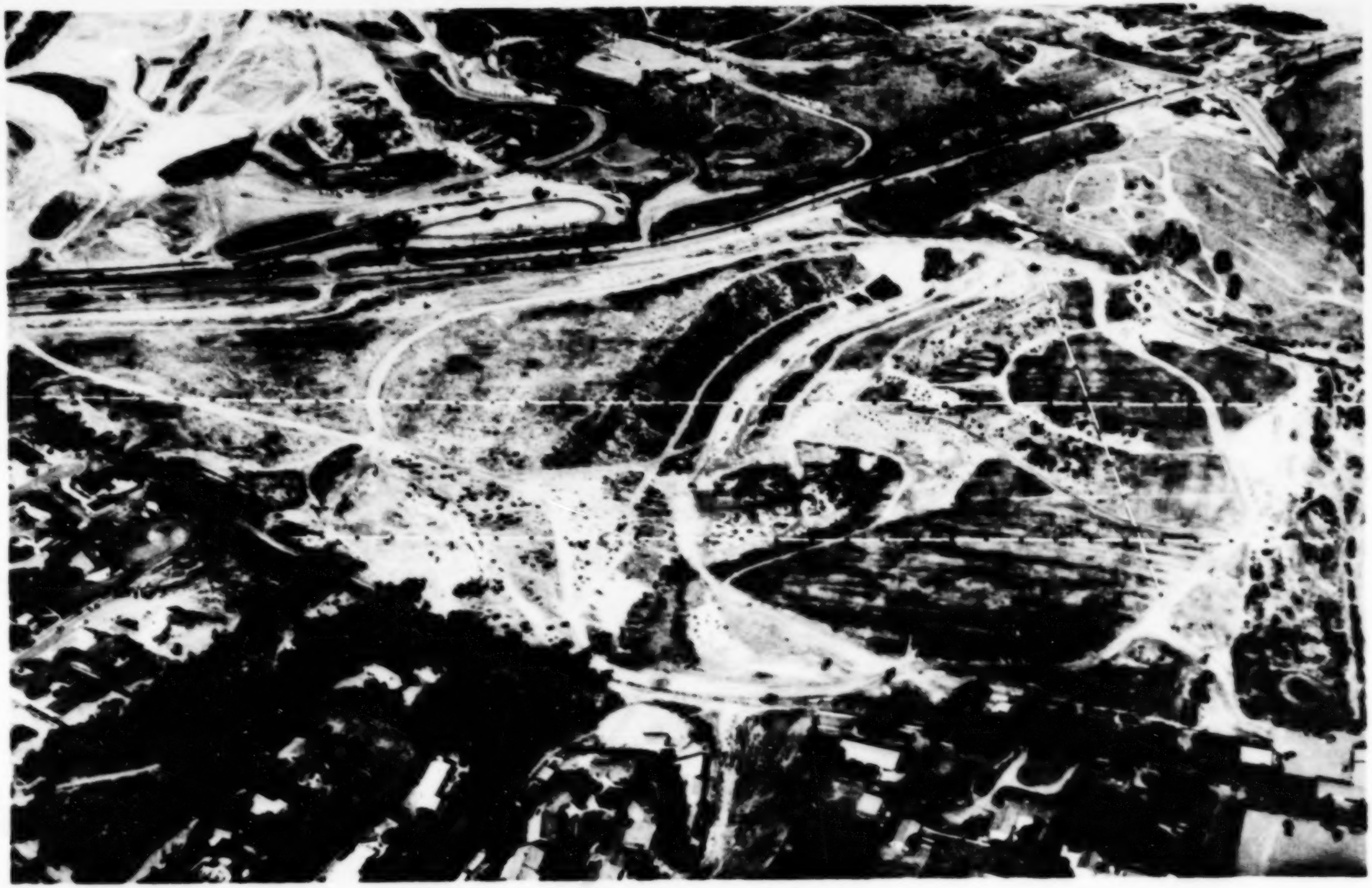
FIGURE III-33


SCALE 1" = 200'
PROFILE LINE "B"
PROFILE LINE "A"
BASE LINE
℄
℄
LEGEND
Fill Limits
Control Monument △
Secondary Monument ◻
Profile Line

MONUMENT
LOCATION
SITE NO. 5

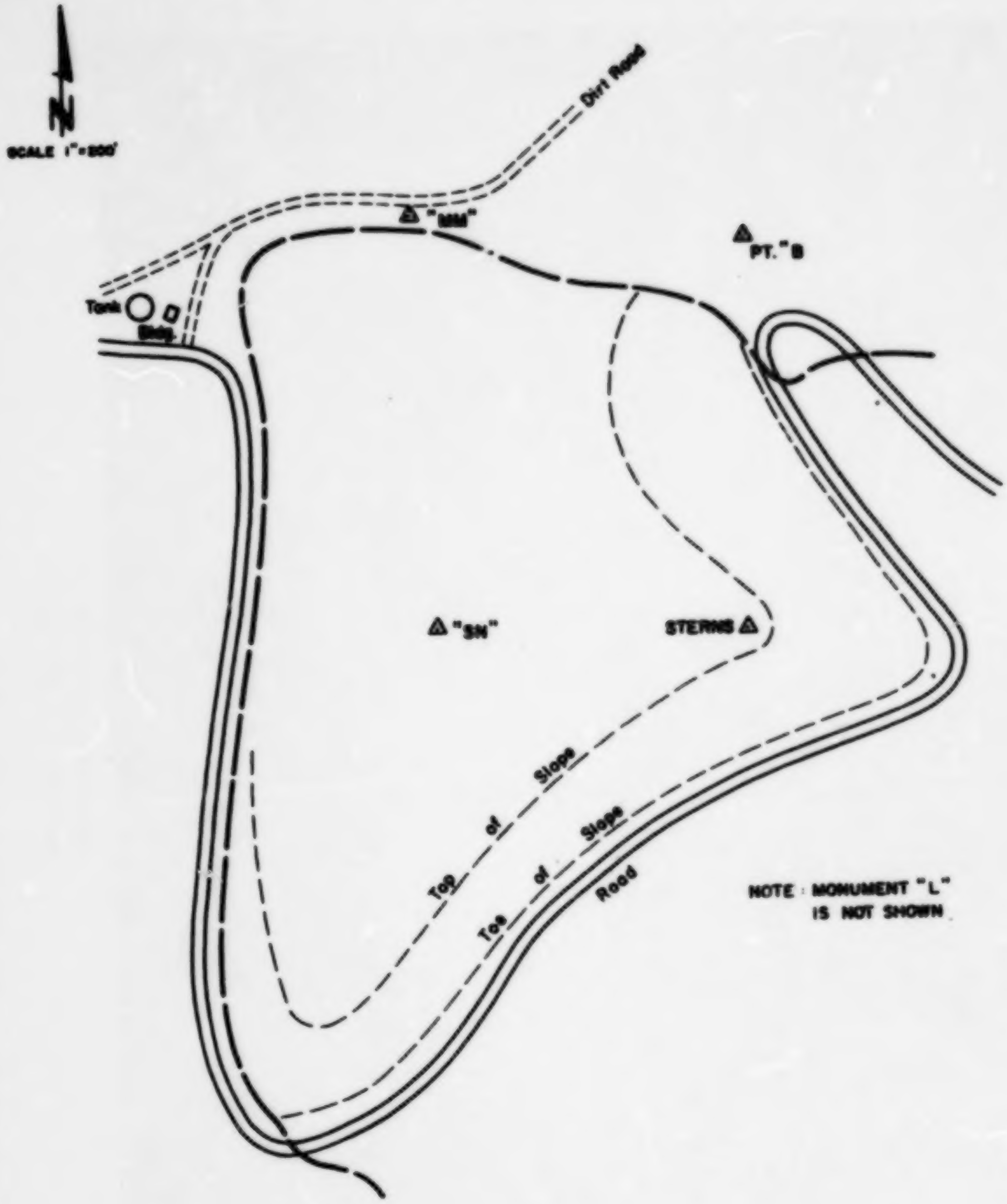
ENGINEERING - SCIENCE, INC.

FIGURE III - 34



RESEARCH SITE NO. 5
Surveying monument system

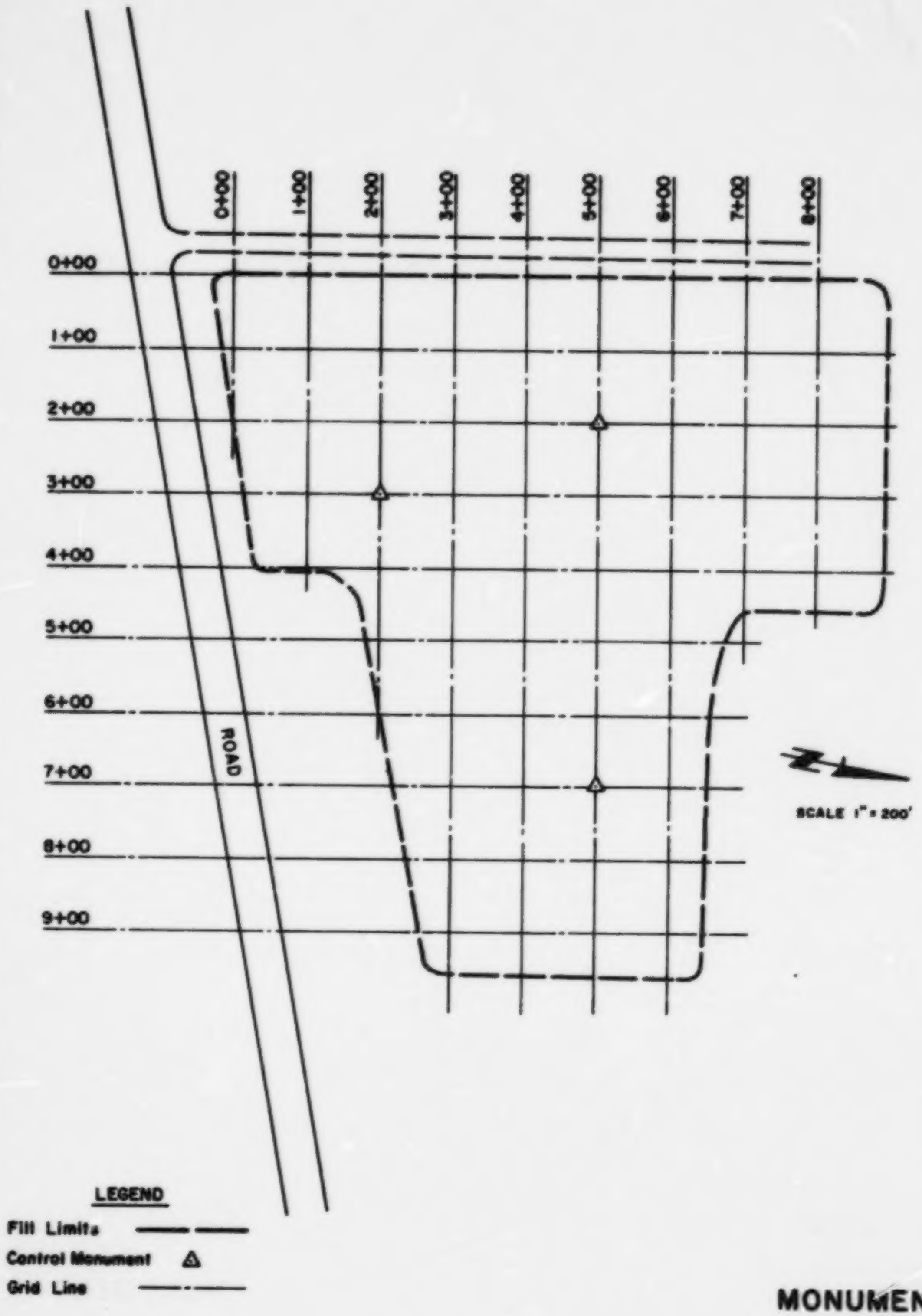
FIGURE III-35


N
SCALE 1"=200'
Dirt Road
"MM"
PT. "B
Tank
Bldg.
"SN"
STERNS
Top of Slope
Toe of Slope
Road
NOTE: MONUMENT "L"
IS NOT SHOWN
LEGEND
Fill Limits
Monument △

MONUMENT
LOCATION
SITE NO. 7

ENGINEERING - SCIENCE, INC.

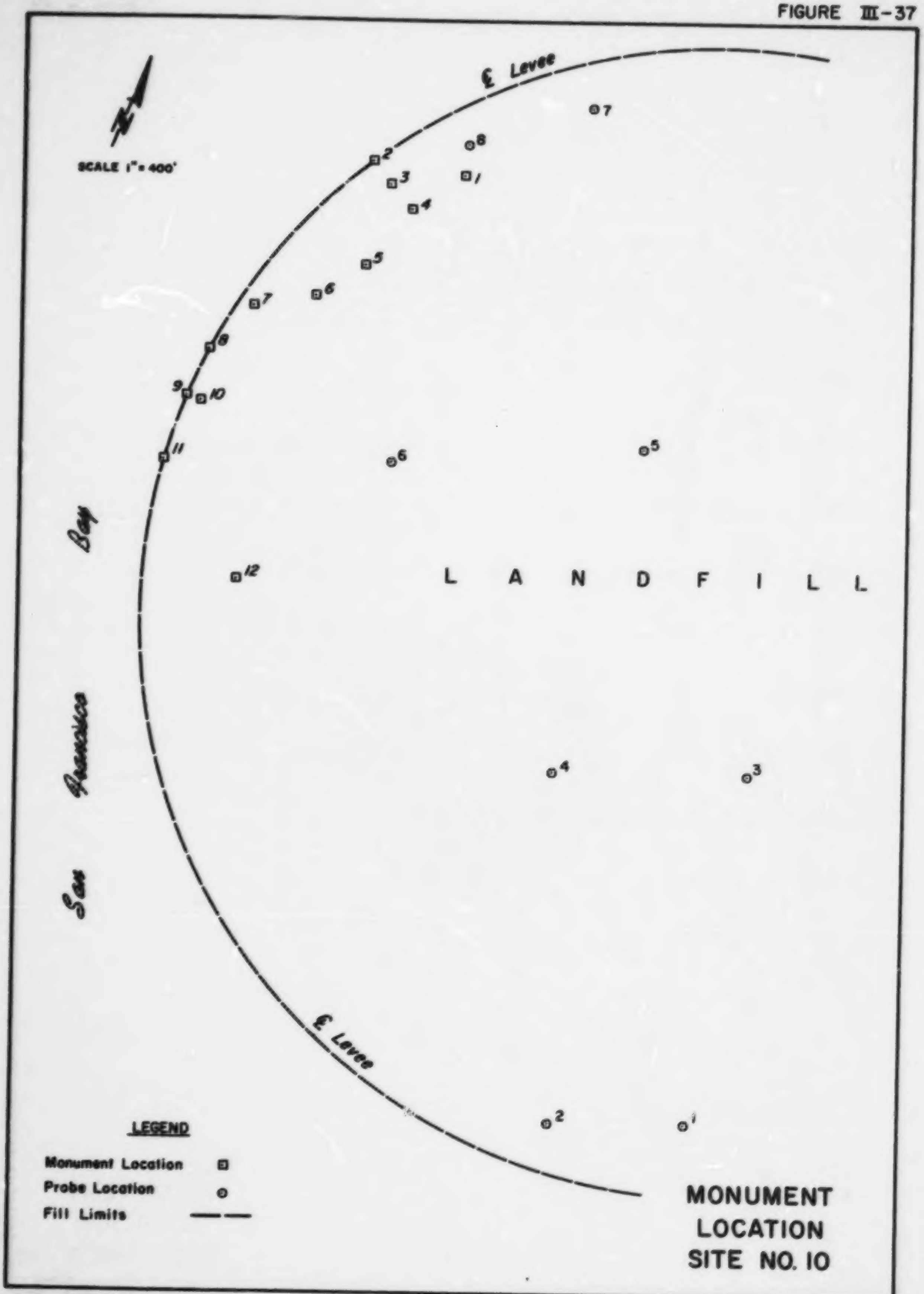
FIGURE III-36


0+00
1+00
2+00
3+00
4+00
5+00
6+00
7+00
8+00
9+00
ROAD
SCALE 1" = 200'
LEGEND
Fill Limits
Control Monument △
Grid Line

MONUMENT
LOCATION
SITE NO. 9

ENGINEERING - SCIENCE, INC.

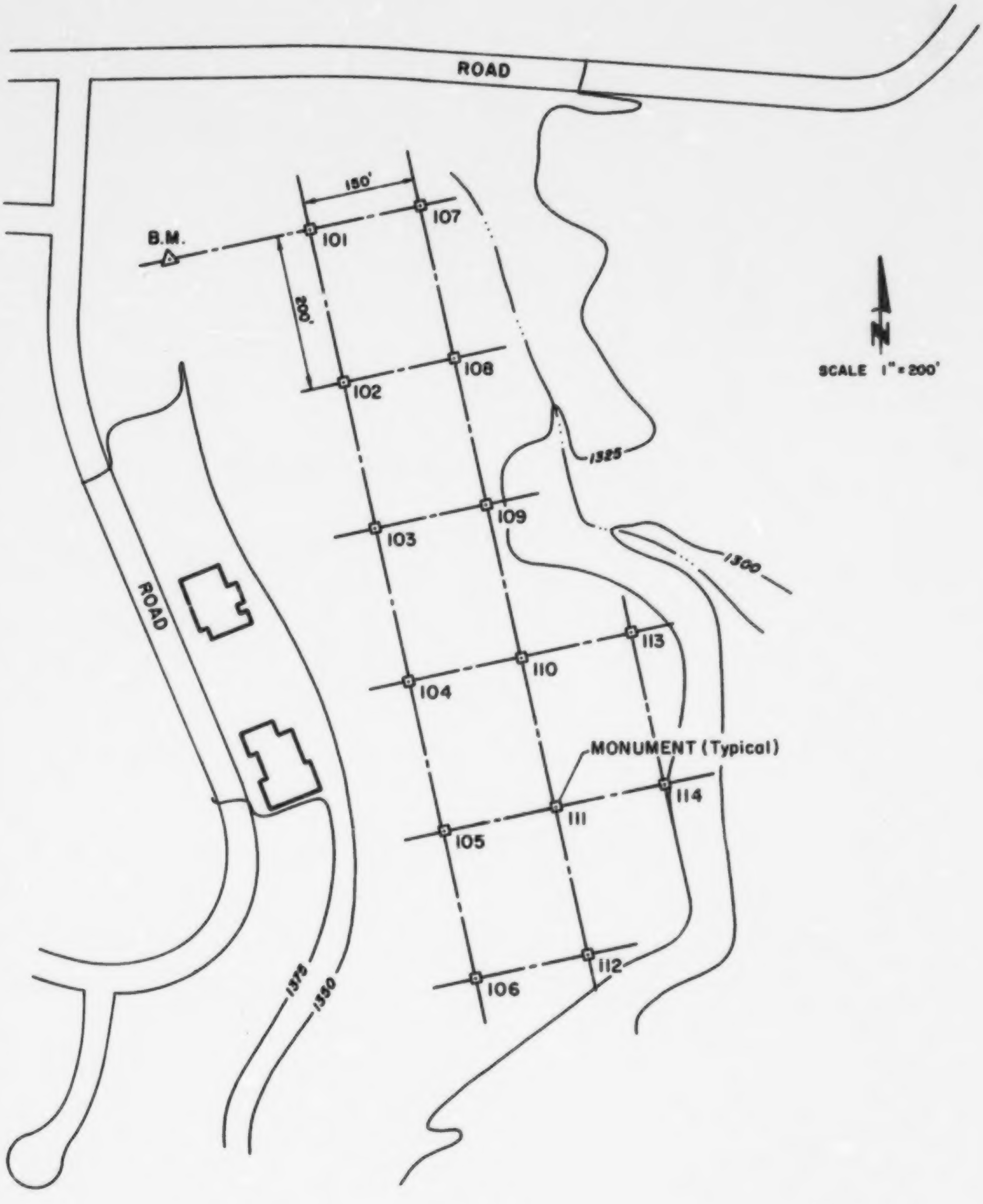
FIGURE III-37


SCALE 1" = 400'
℄ Levee
℄ Levee
San Francisco Bay
LANDFILL
1
2
3
4
5
6
7
8
9
10
11
12
1
2
3
4
5
6
7
8
LEGEND
Monument Location ⊡
Probe Location ⊙
Fill Limits — —

MONUMENT
LOCATION
SITE NO. 10

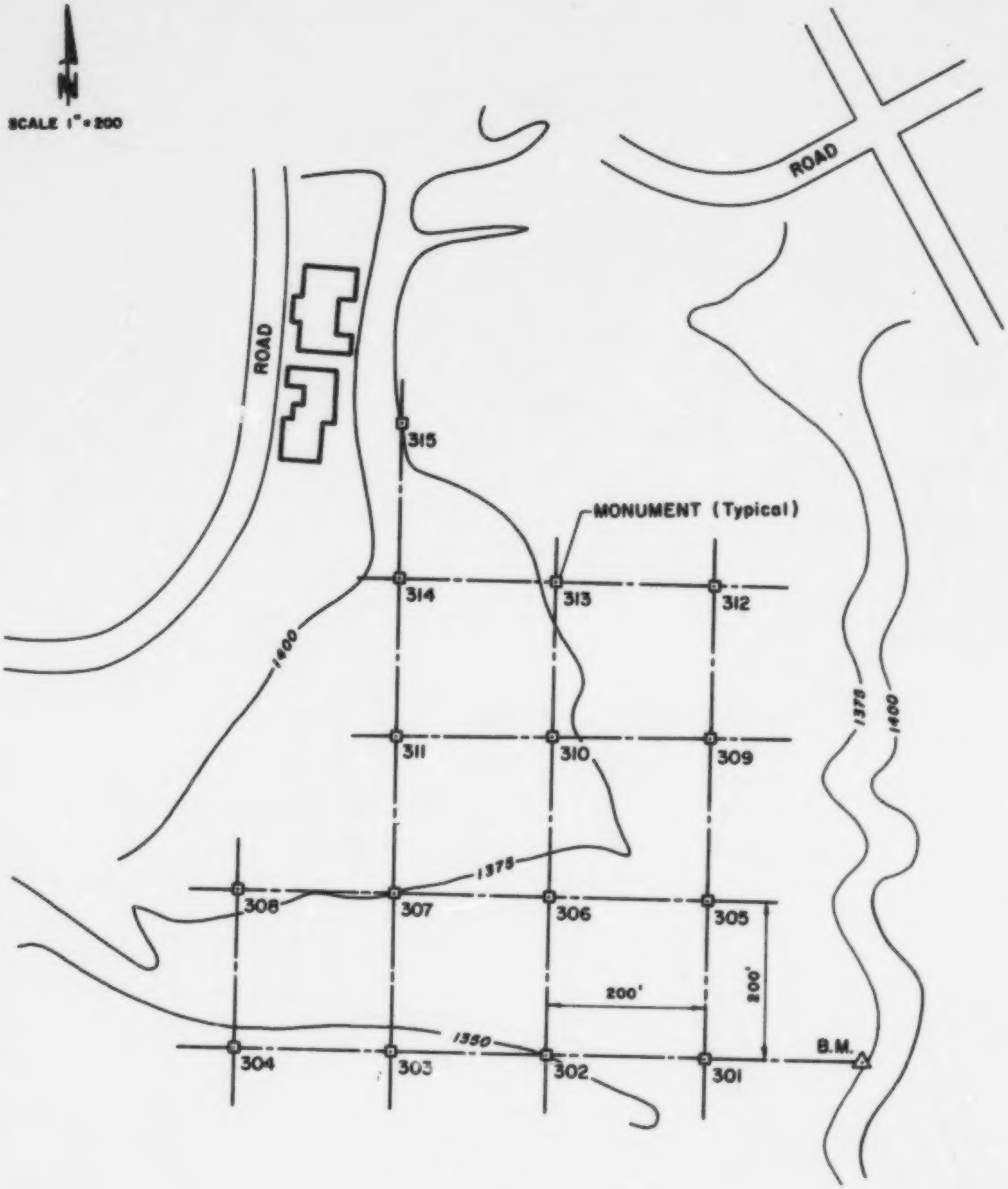
ENGINEERING-SCIENCE, INC.

FIGURE III-38


ROAD
ROAD
B.M.
150'
200'
101
102
103
104
105
106
107
108
109
110
111
112
113
114
MONUMENT (Typical)
1325
1300
1375
1350
N
SCALE 1" = 200'

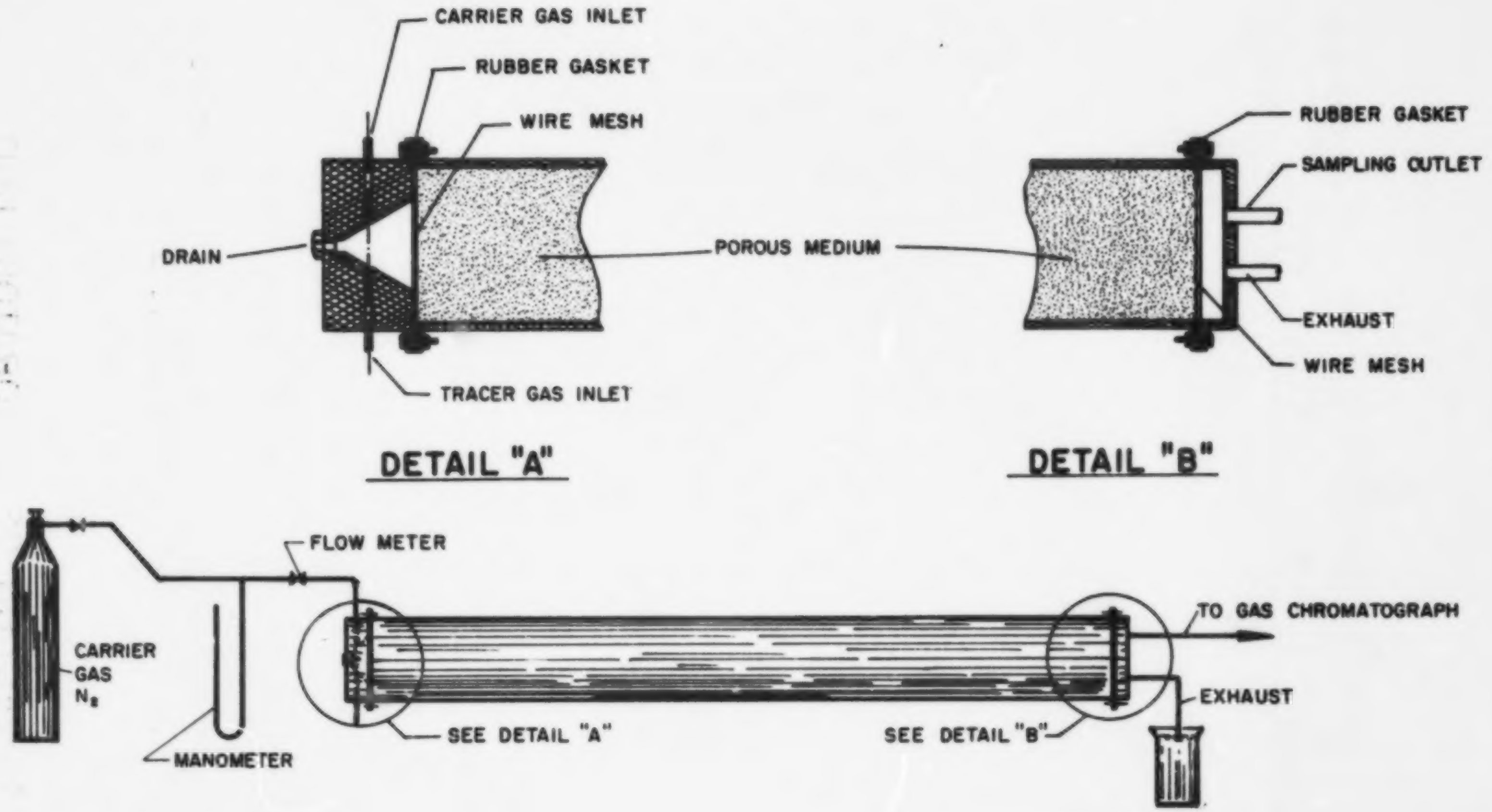
MONUMENT
LOCATION
SITE NO. 11 (AREA 1)

FIGURE III-39

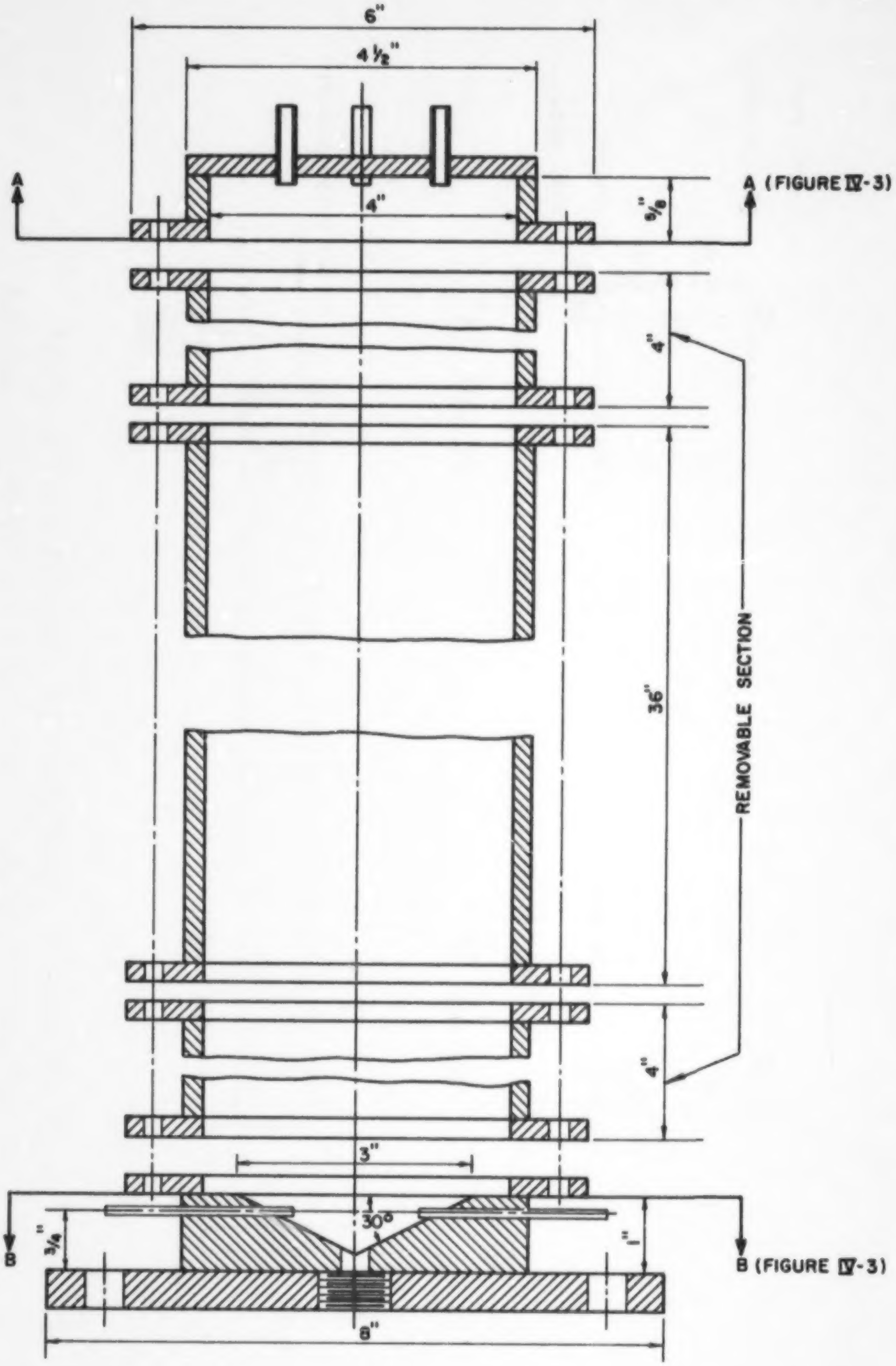

N
SCALE 1" = 200
ROAD
ROAD
315
MONUMENT (Typical)
314
313
312
1400
311
310
309
1375
1400
1375
308
307
306
305
200'
200'
1350
B.M.
304
303
302
301

MONUMENT
LOCATION
SITE NO. 11 (AREA 3)

FIGURE IV-1


CARRIER GAS INLET
RUBBER GASKET
WIRE MESH
DRAIN
POROUS MEDIUM
TRACER GAS INLET
RUBBER GASKET
SAMPLING OUTLET
EXHAUST
WIRE MESH
DETAIL "A"
DETAIL "B"
FLOW METER
CARRIER GAS N₂
MANOMETER
SEE DETAIL "A"
SEE DETAIL "B"
TO GAS CHROMATOGRAPH
EXHAUST

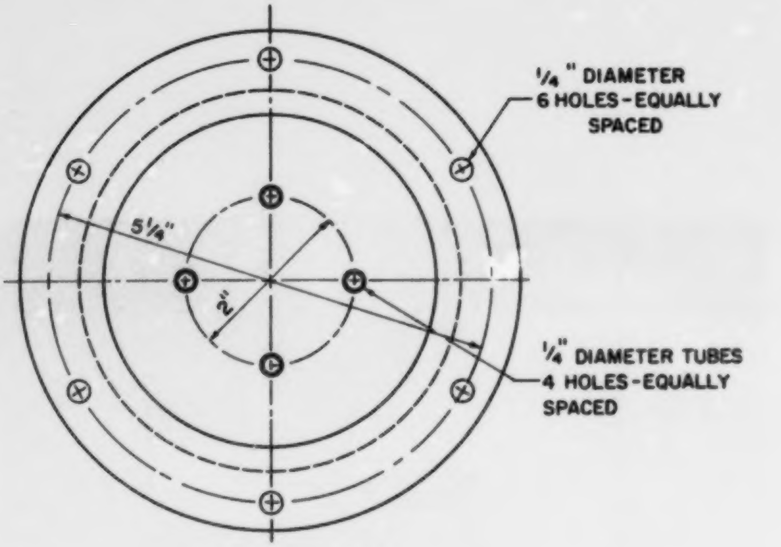
SCHEMATIC DIAGRAM OF LABORATORY UNIT
FOR STUDY OF GAS DIFFUSION IN POROUS MEDIA


6"
4 1/2"
4"
5/8"
A
A (FIGURE IV-3)
4"
36"
4"
REMOVABLE SECTION
3"
30°
3/4"
1"
B
B (FIGURE IV-3)
8"

CROSS-SECTION OF LABORATORY UNIT

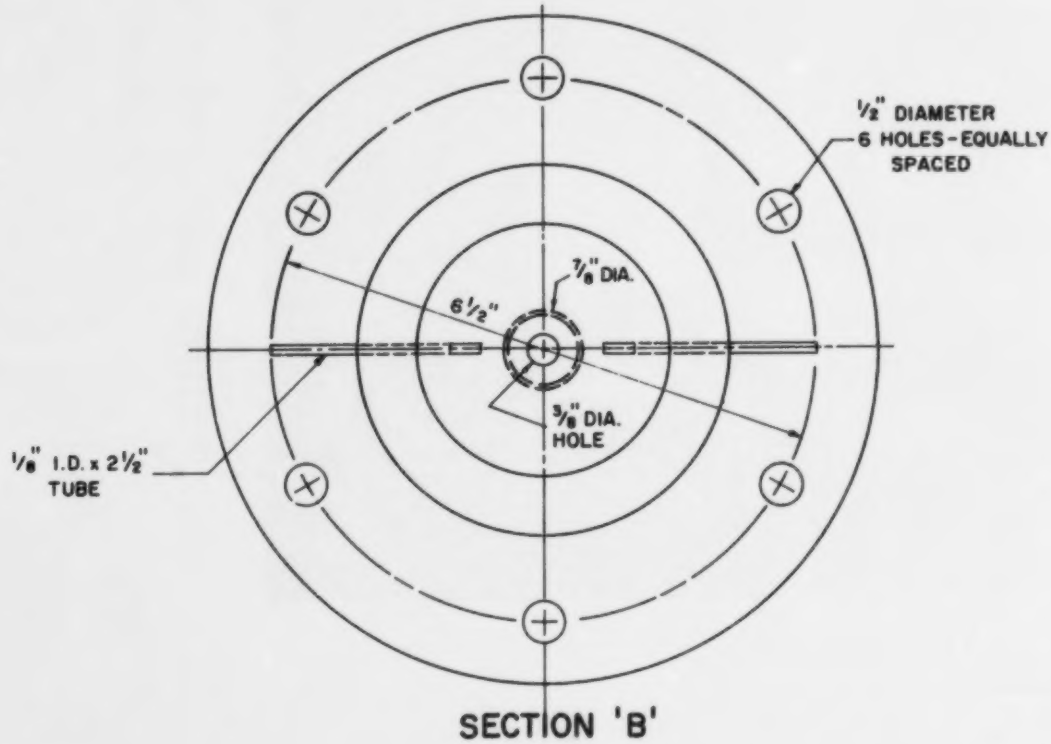
ENGINEERING - SCIENCE, INC.

FIGURE IV-3



1/4" DIAMETER
6 HOLES-EQUALLY SPACED
5 1/4"
2"
1/4" DIAMETER TUBES
4 HOLES-EQUALLY SPACED

SECTION 'A'

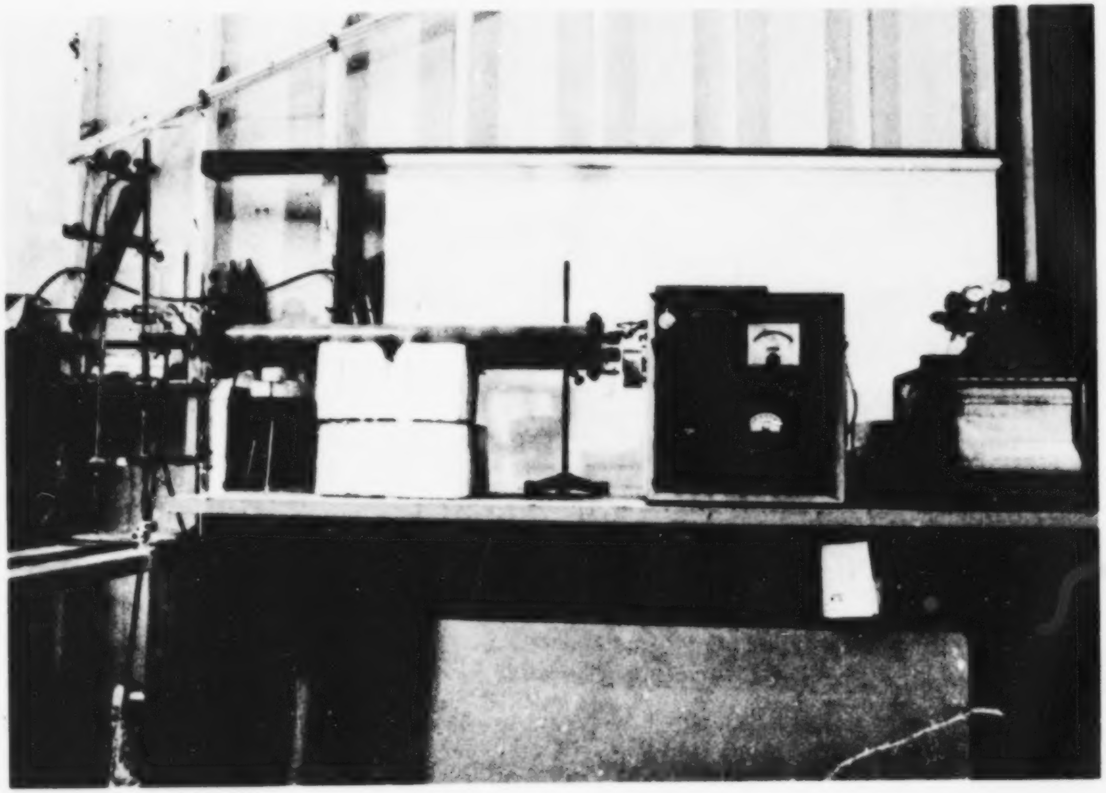


1/2" DIAMETER
6 HOLES-EQUALLY SPACED
7/8" DIA.
6 1/2"
3/8" DIA. HOLE
1/8" I.D. x 2 1/2" TUBE

SECTION 'B'

SECTIONS THROUGH LABORATORY UNIT

FIGURE IV-4



LABORATORY UNIT FOR STUDY OF GAS DIFFUSION
IN POROUS MEDIA

FIGURE IV-5

GRAIN SIZE DISTRIBUTION - SAND

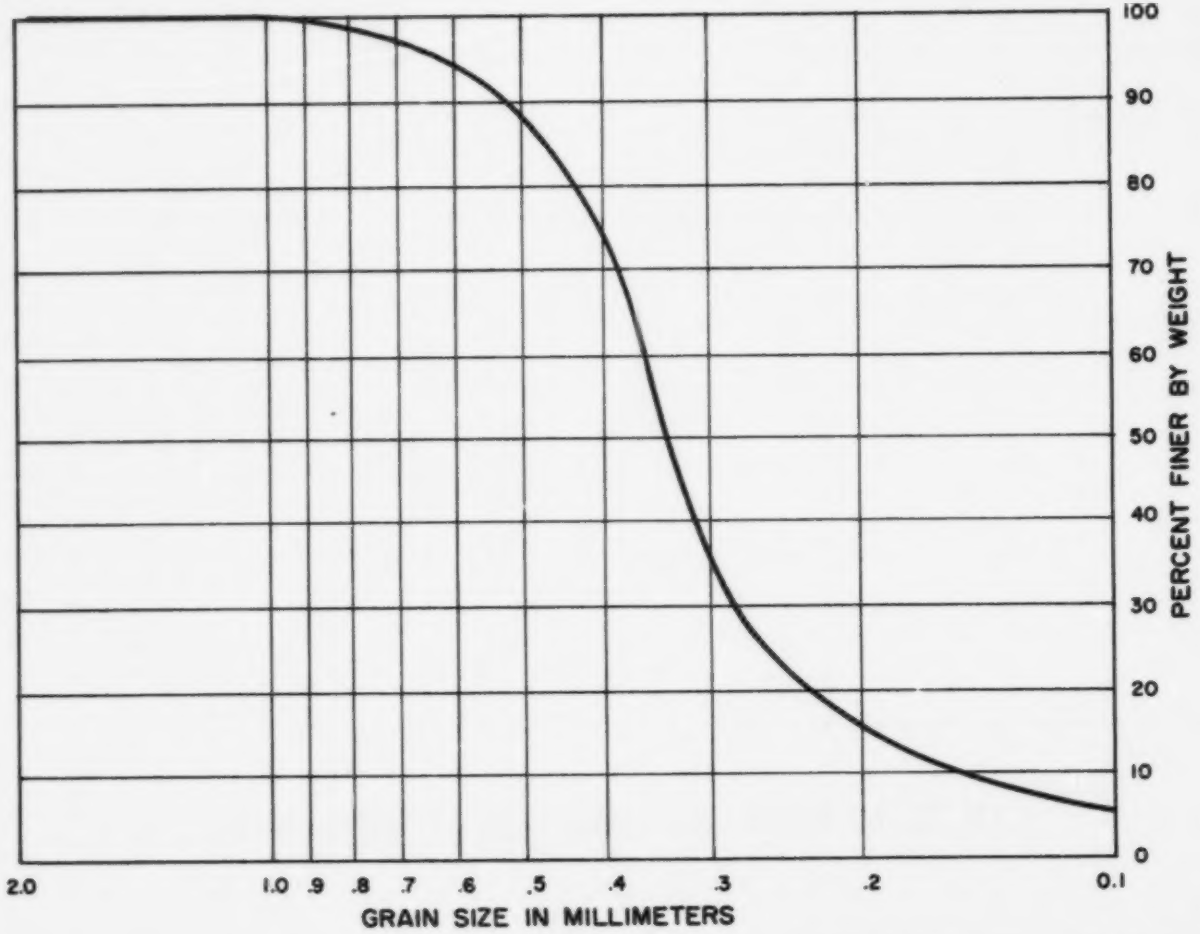


FIGURE IV-6

GRAIN SIZE DISTRIBUTION - KAOLIN CLAY

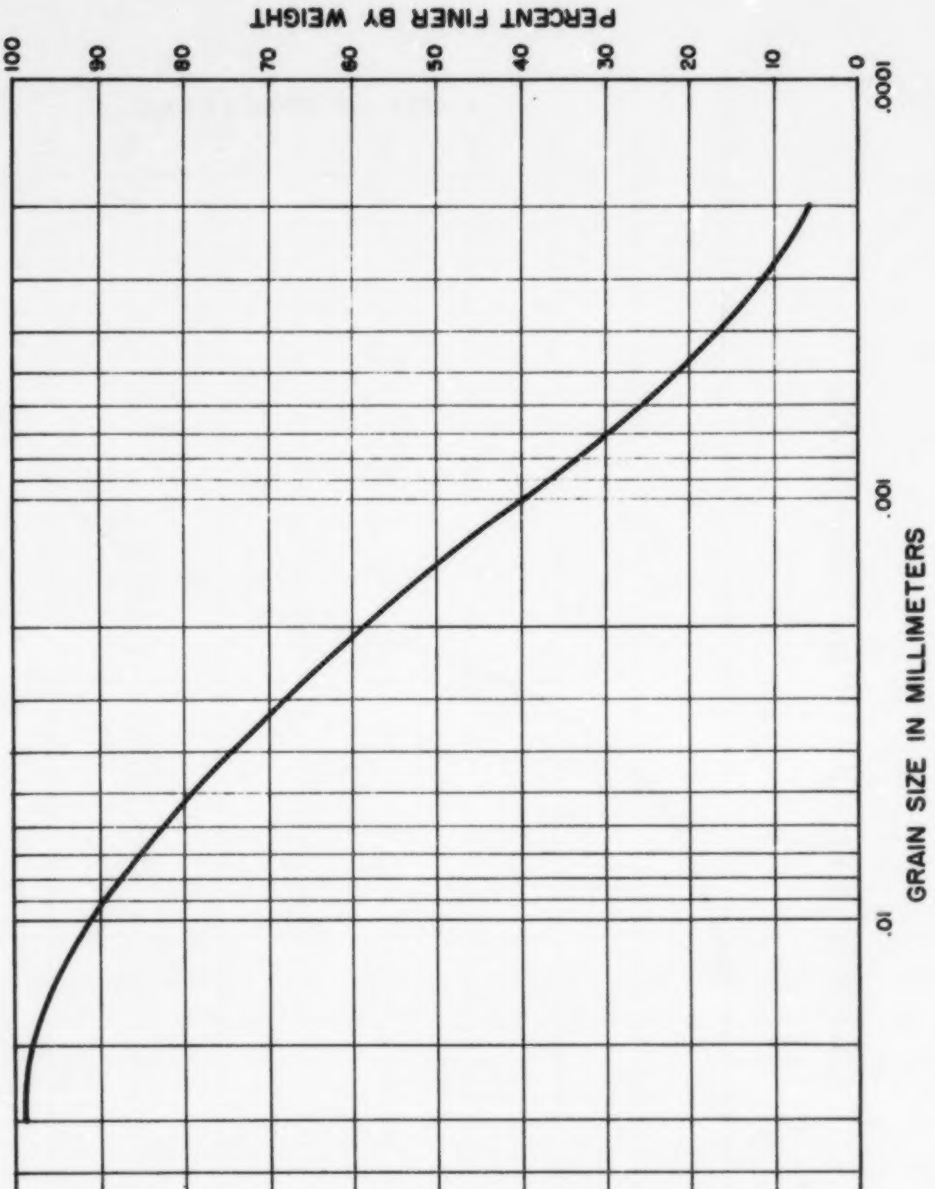


FIGURE IV-7

METHANE CONCENTRATION HISTORY - TEST NO. 1

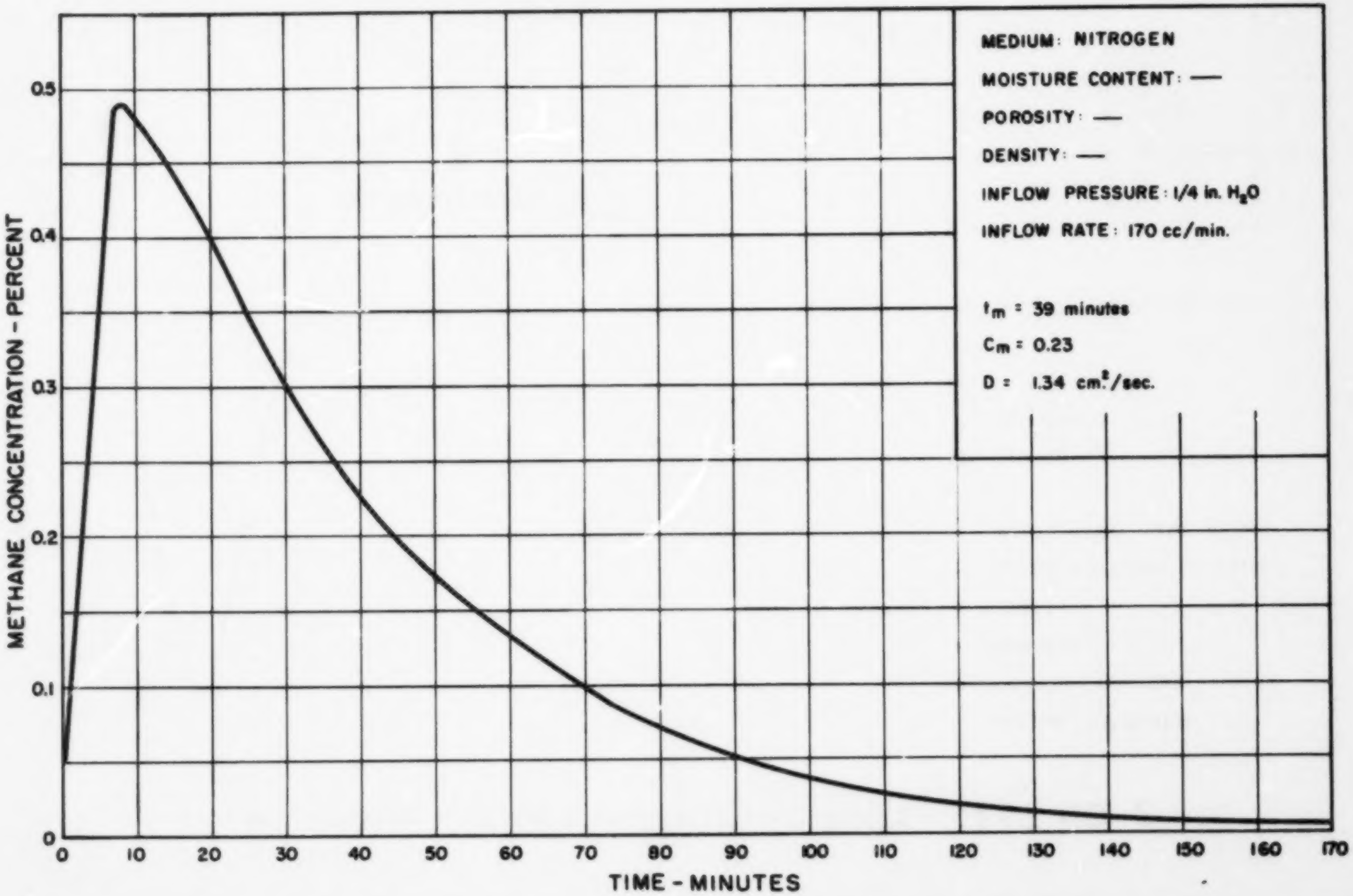
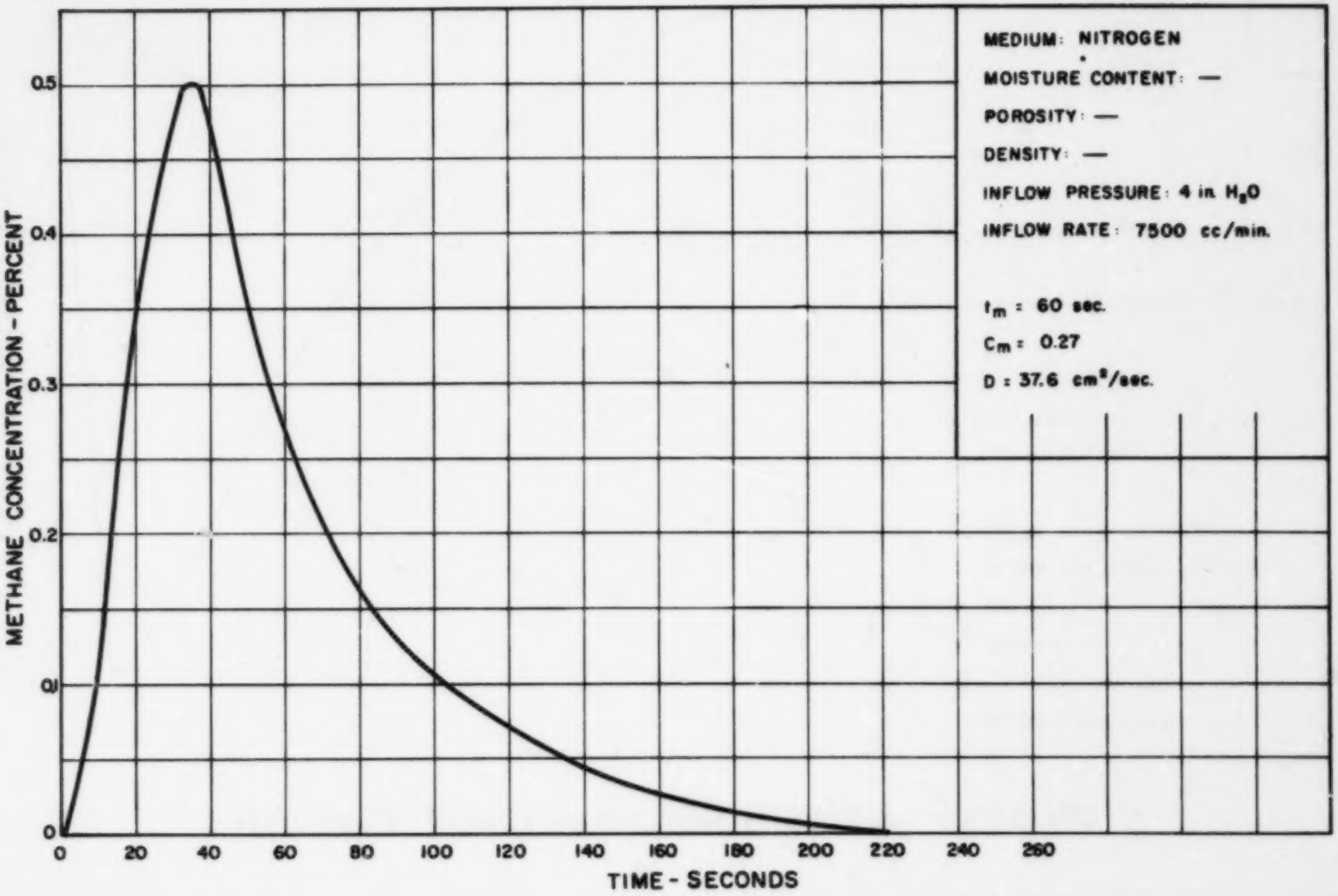


FIGURE IV-8

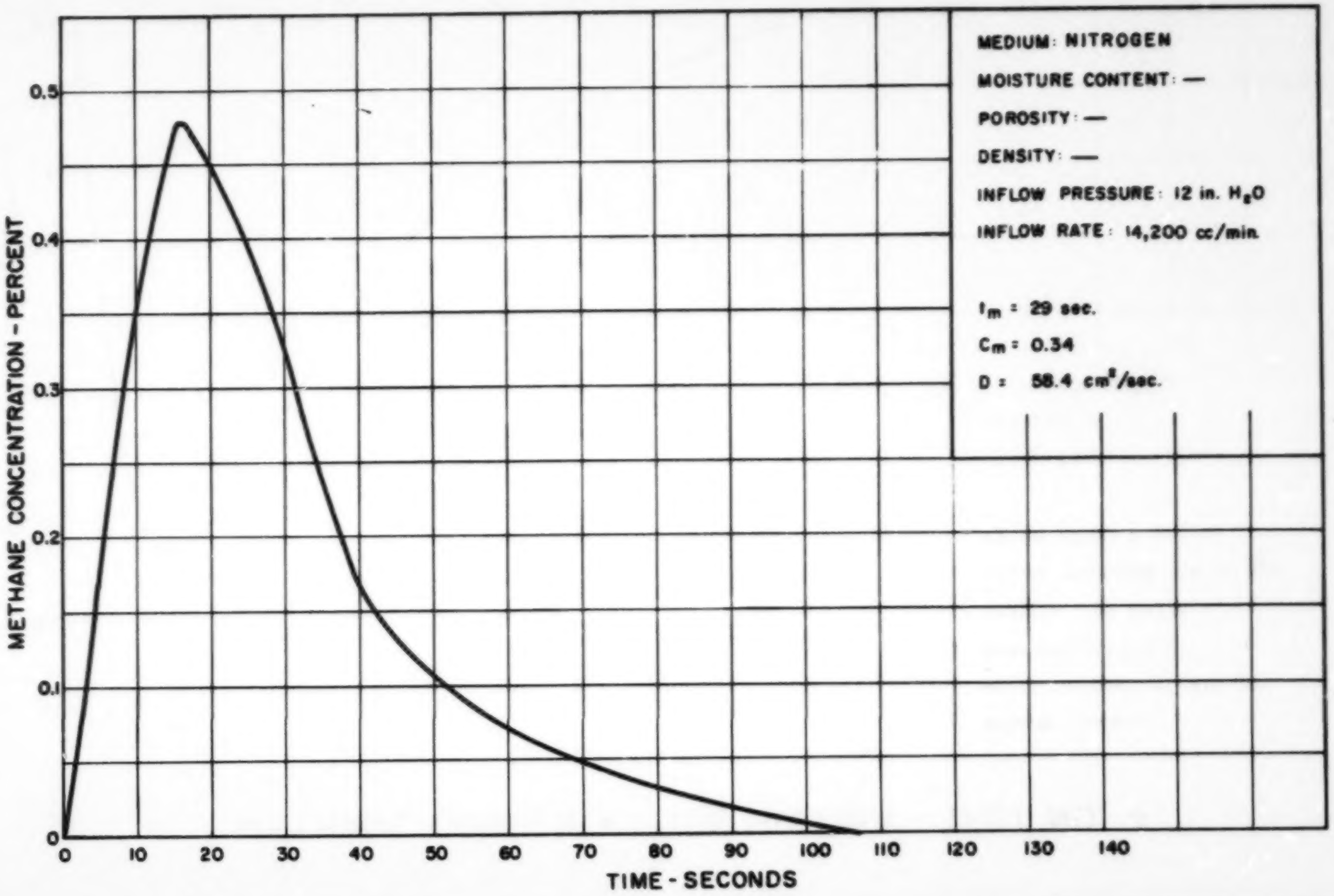
METHANE CONCENTRATION HISTORY - TEST NO. 2



ENGINEERING-SCIENCE, INC.

FIGURE IV-9

METHANE CONCENTRATION HISTORY - TEST NO. 3



ENGINEERING-SCIENCE, INC.

FIGURE IV-10

METHANE CONCENTRATION HISTORY - TEST NO. 4

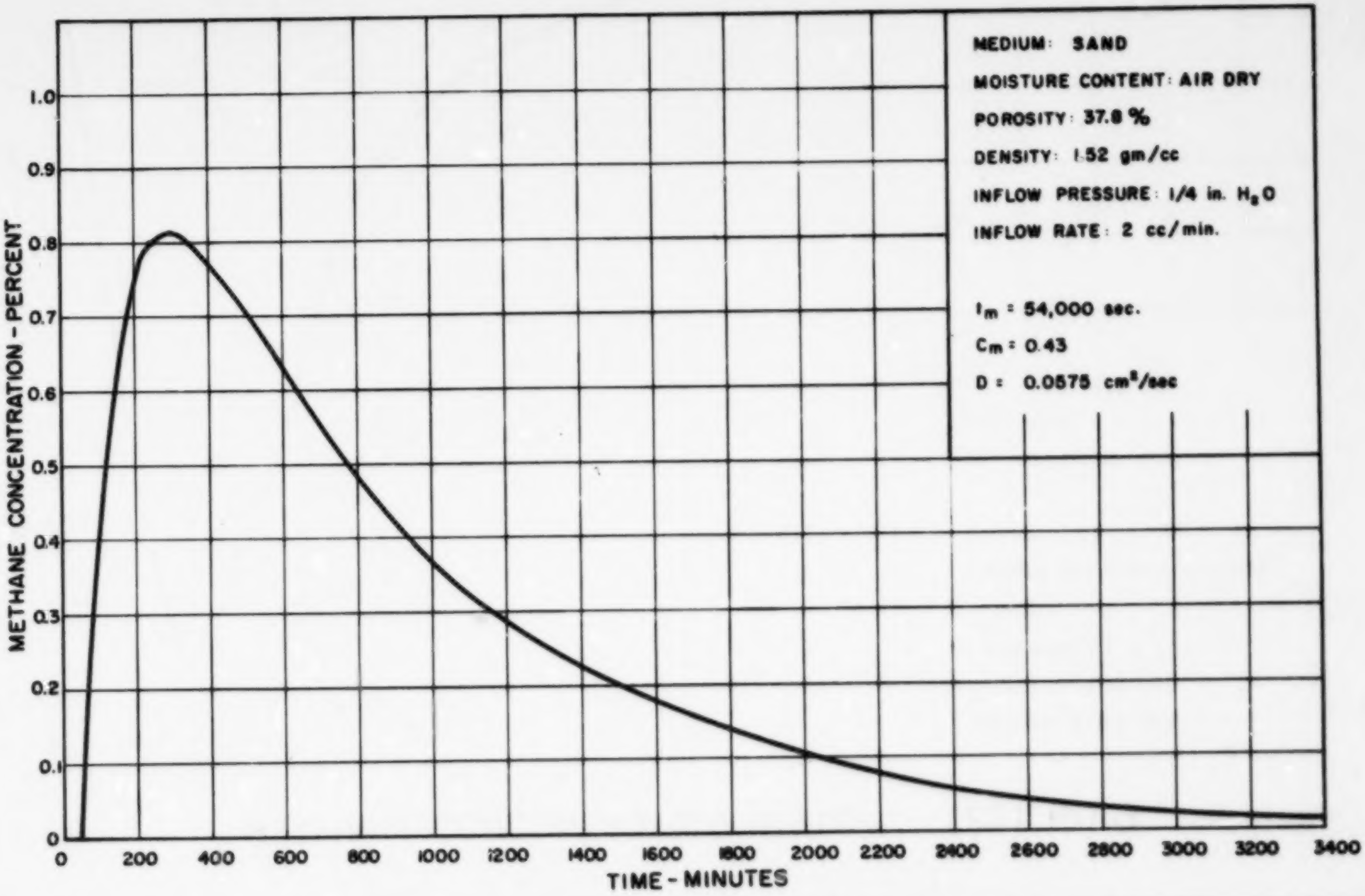


FIGURE IV-11

METHANE CONCENTRATION HISTORY - TEST NO. 5

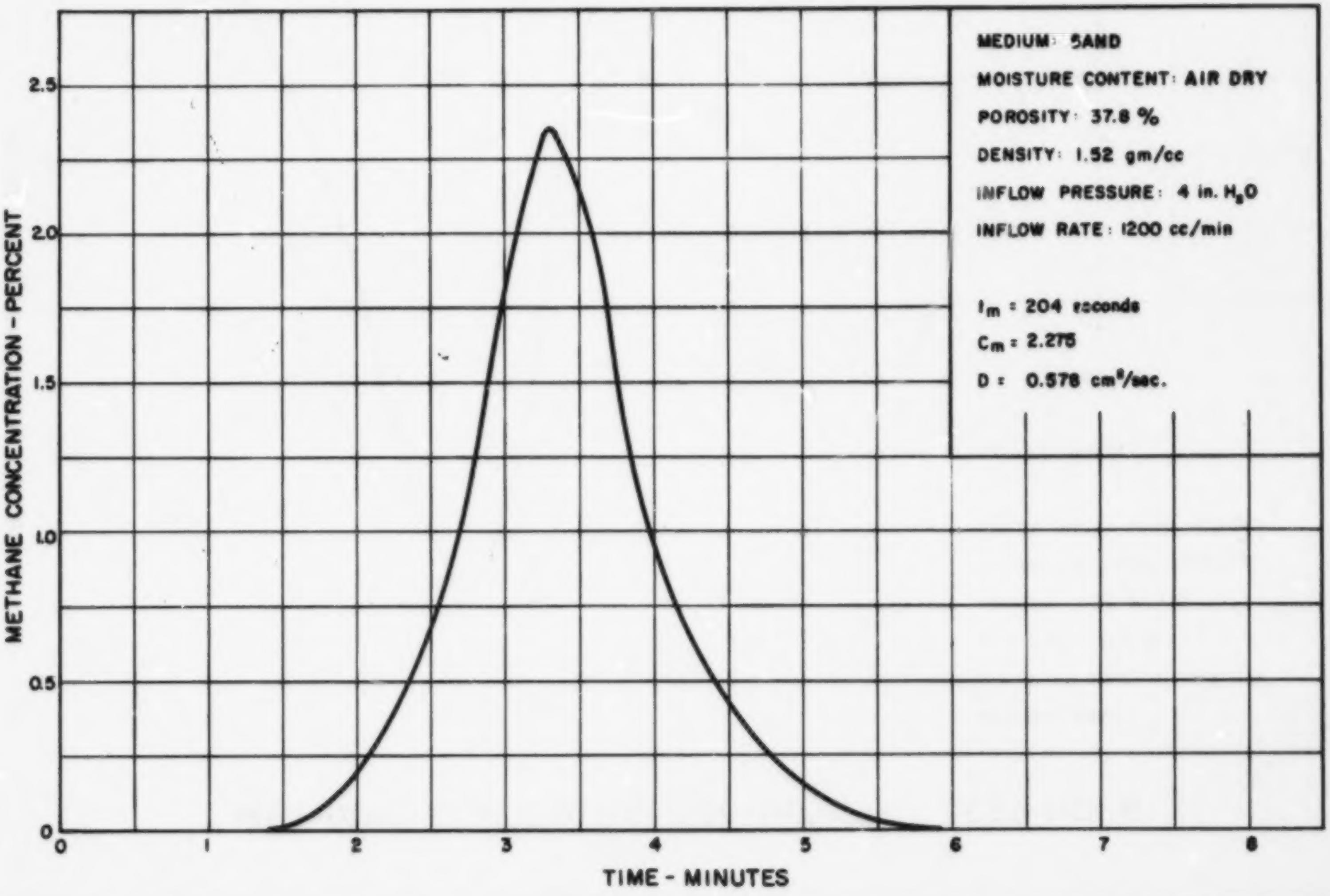
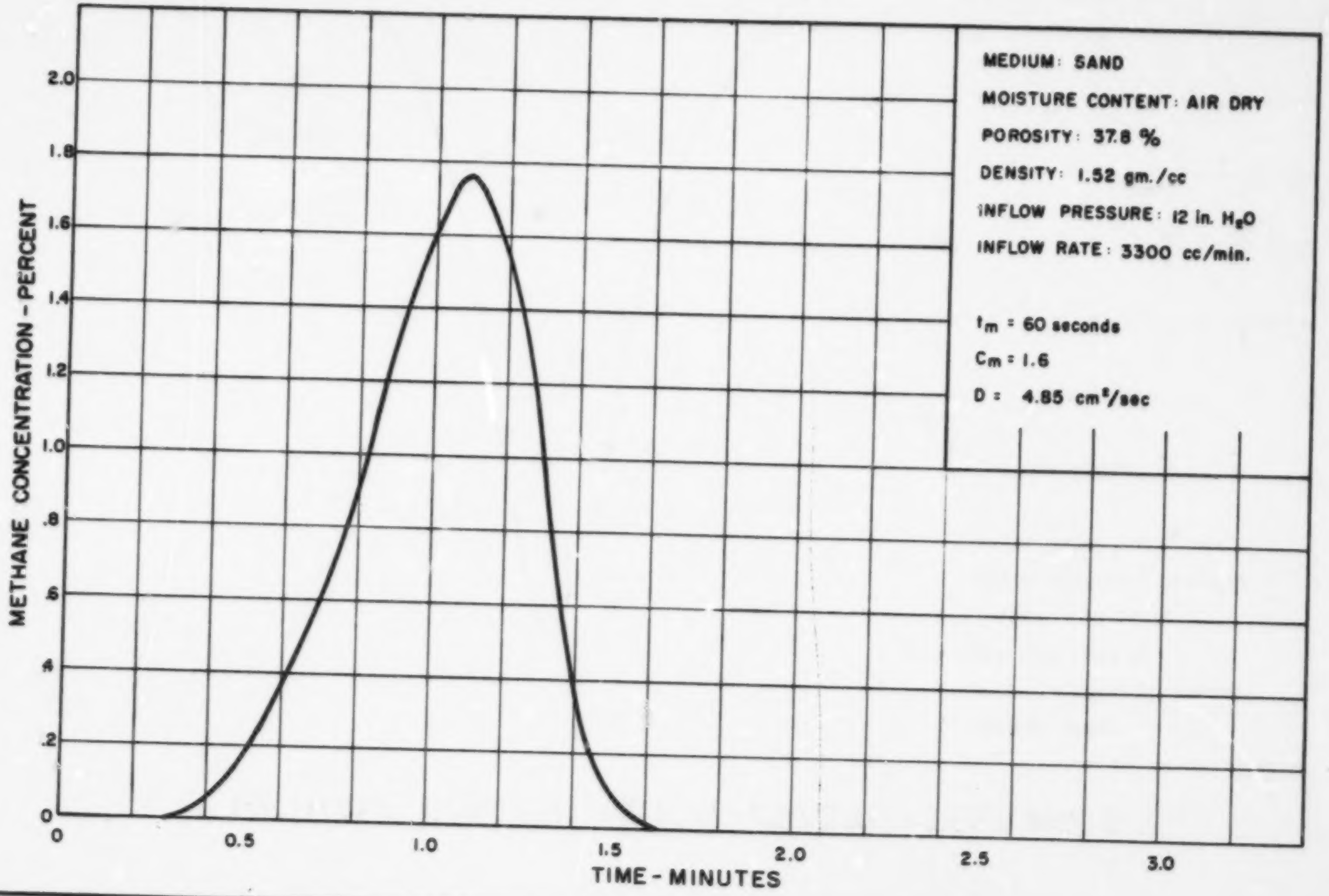
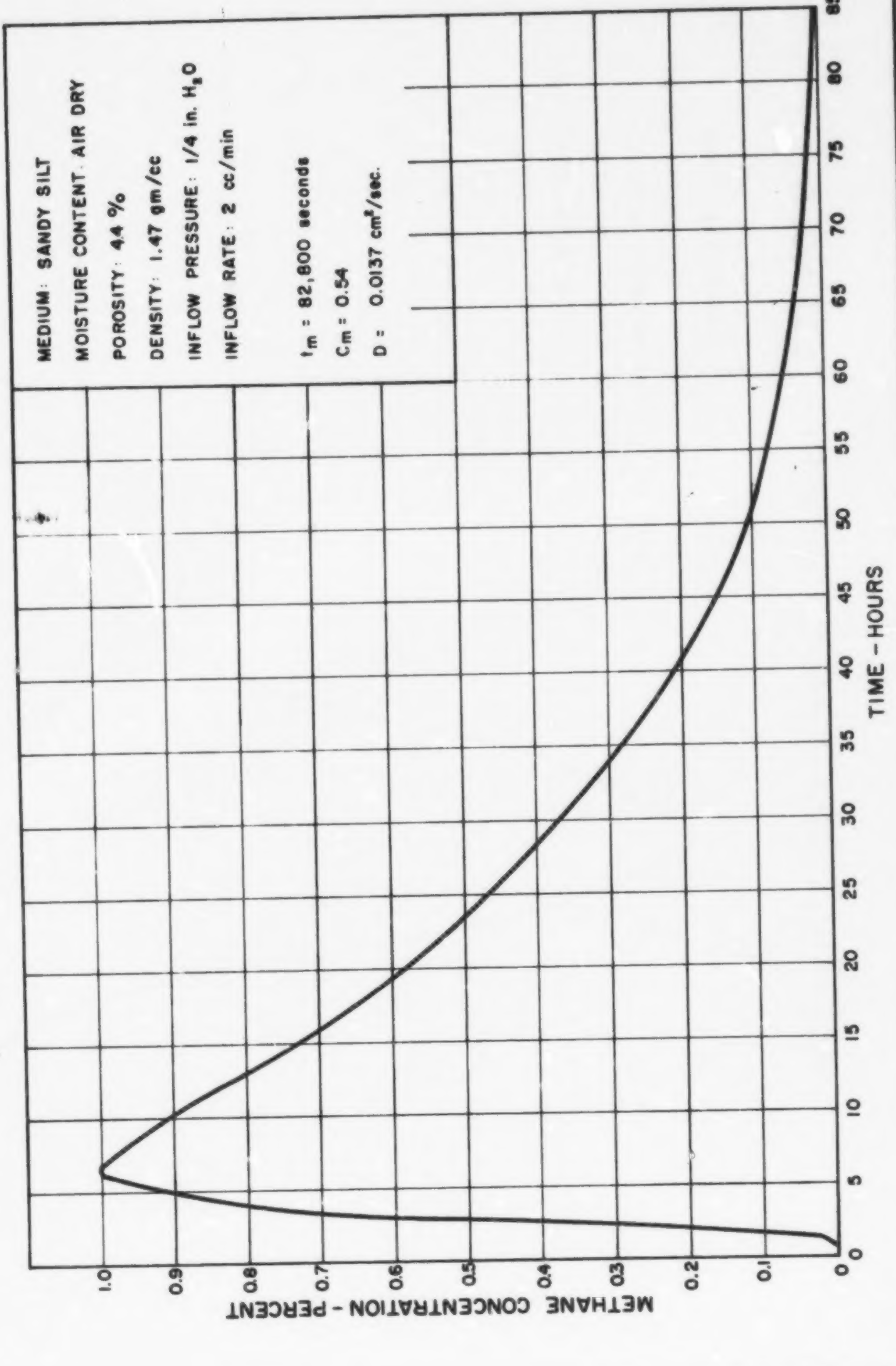


FIGURE IV-12

METHANE CONCENTRATION HISTORY - TEST NO. 6



METHANE CONCENTRATION HISTORY - TEST NO. 7

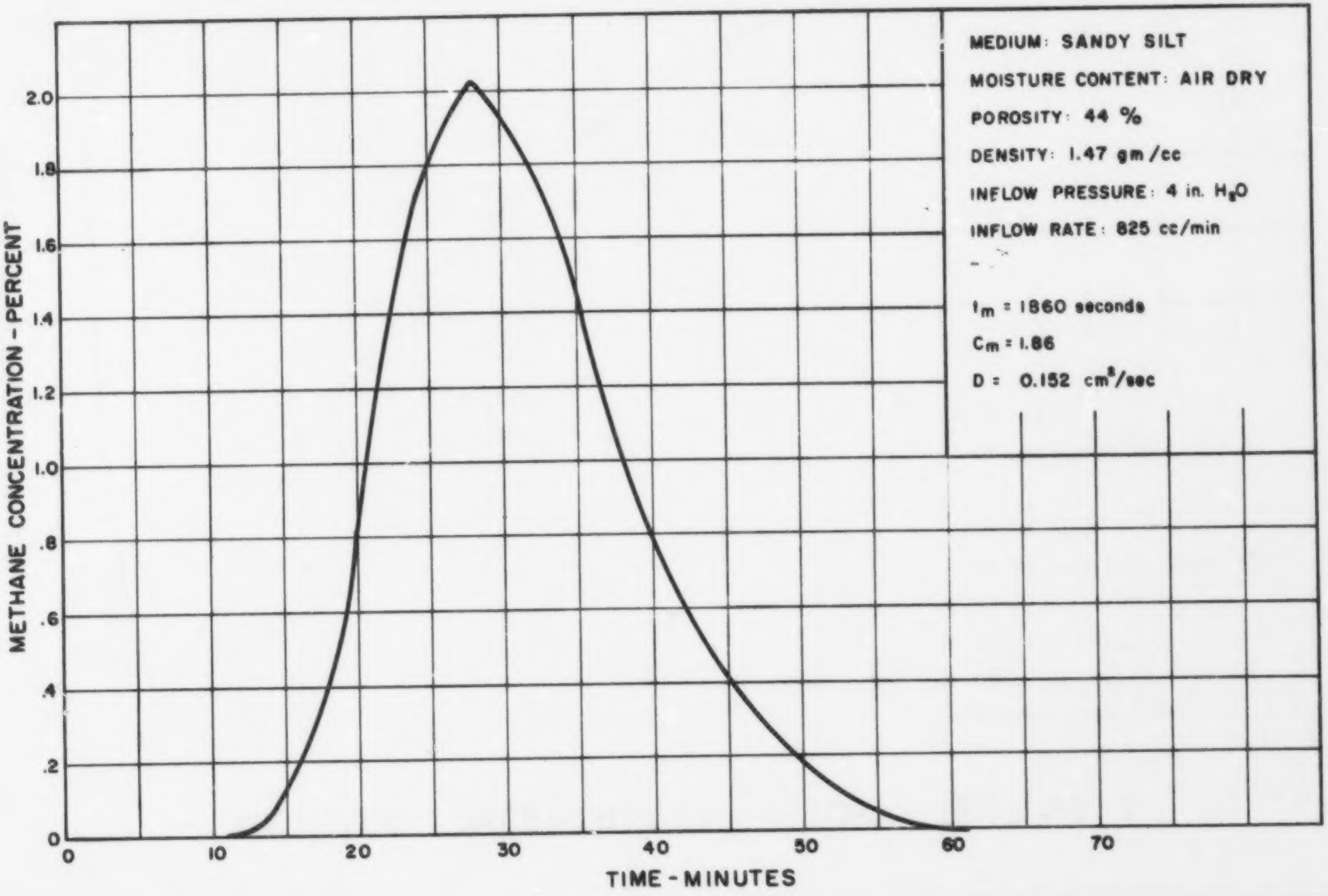


MEDIUM: SANDY SILT
MOISTURE CONTENT: AIR DRY
POROSITY: 44 %
DENSITY: 1.47 gm/cc
INFLOW PRESSURE: 1/4 in. H_2O
INFLOW RATE: 2 cc/min

t_m = 82,800 seconds
C_m = 0.54
D = 0.0137 cm^2/sec.

FIGURE IV-14

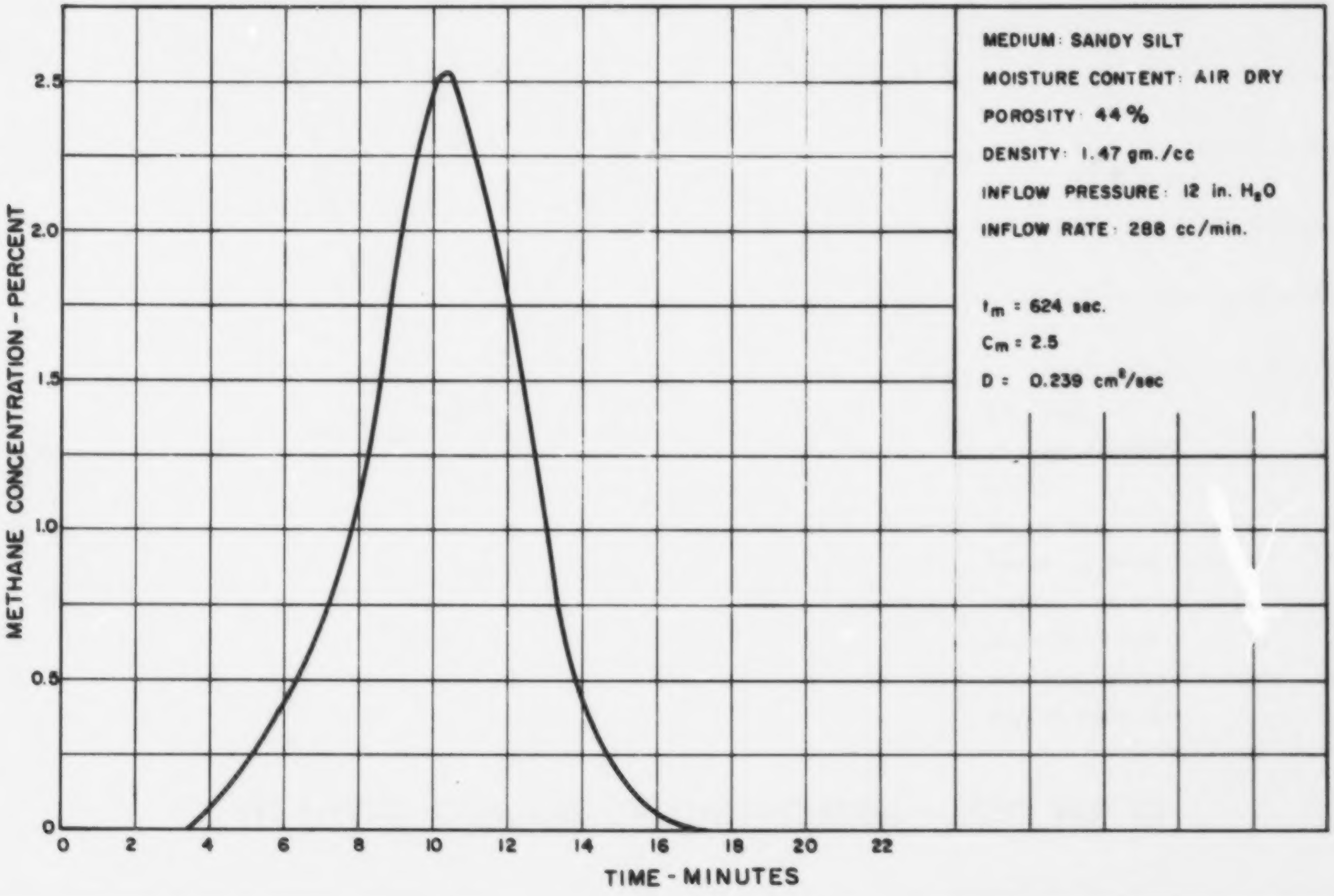
METHANE CONCENTRATION HISTORY - TEST NO. 8



ENGINEERING-SCIENCE, INC.

FIGURE IV-15

METHANE CONCENTRATION HISTORY - TEST NO. 9



ENGINEERING-SCIENCE, INC.

FIGURE IV-16

METHANE CONCENTRATION HISTORY - TEST NO. 10

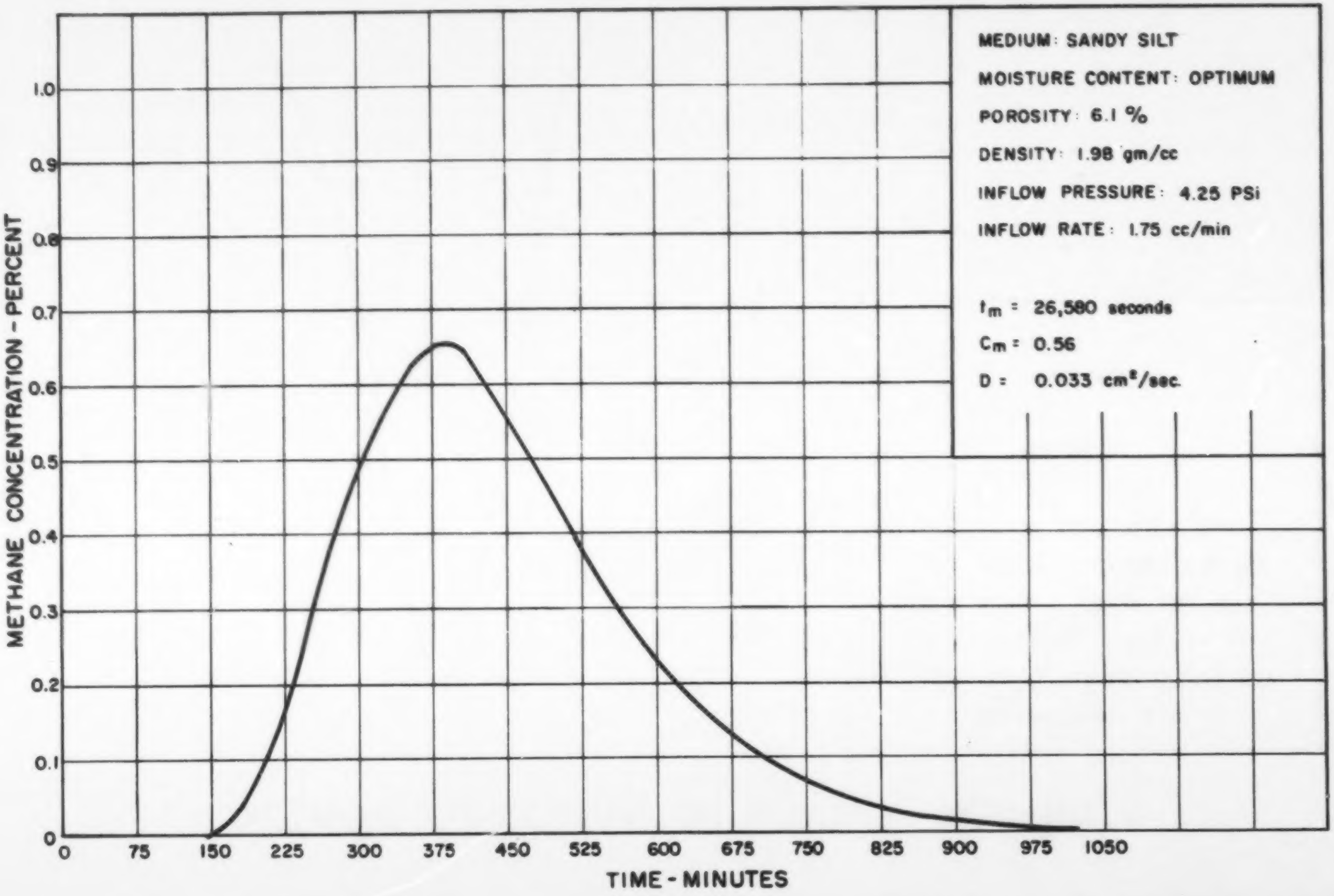
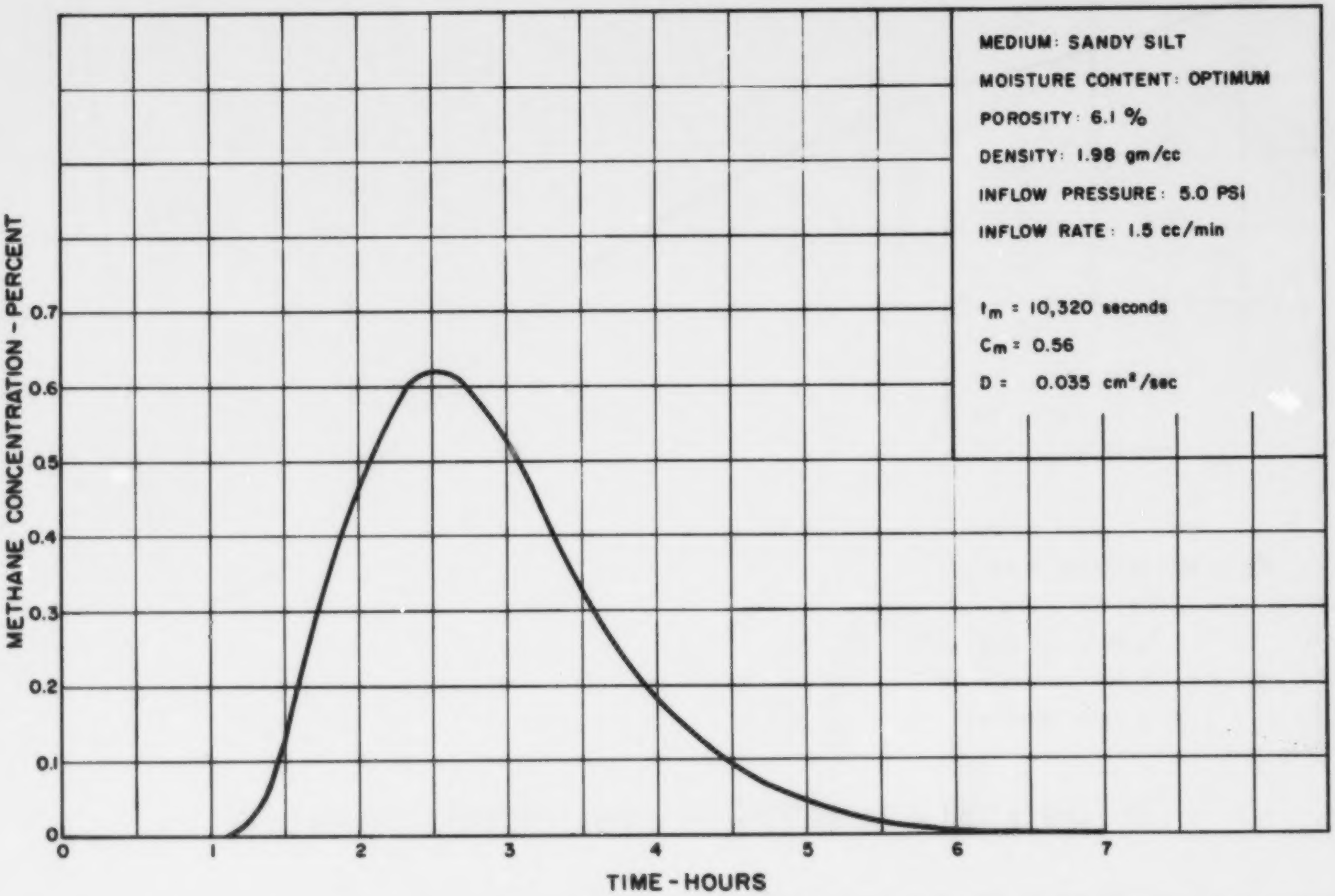


FIGURE IV-17

METHANE CONCENTRATION HISTORY - TEST NO. II



ENGINEERING-SCIENCE, INC.

METHANE CONCENTRATION HISTORY - TEST NO. 12

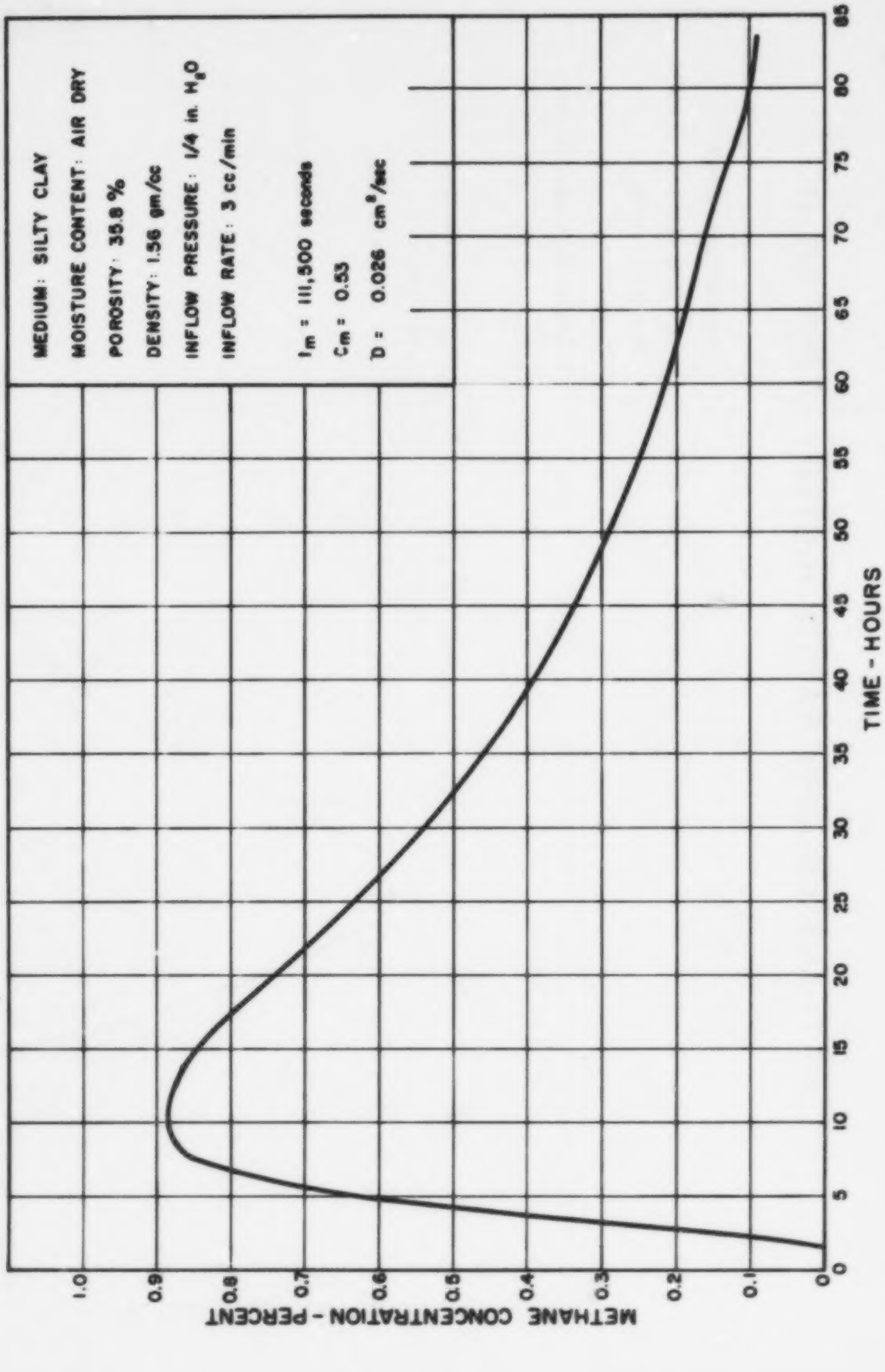


FIGURE IV-19

METHANE CONCENTRATION HISTORY - TEST NO. 13

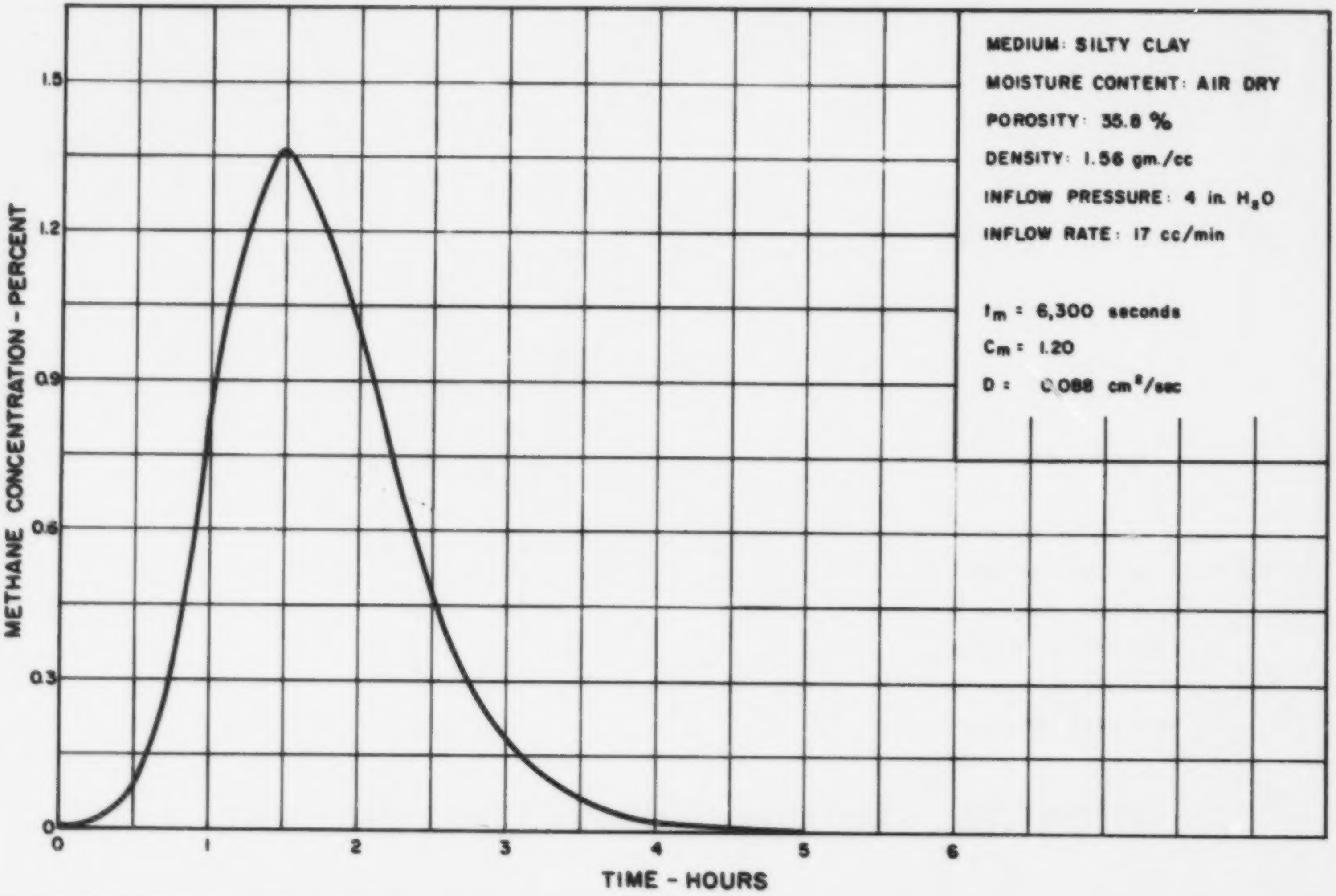
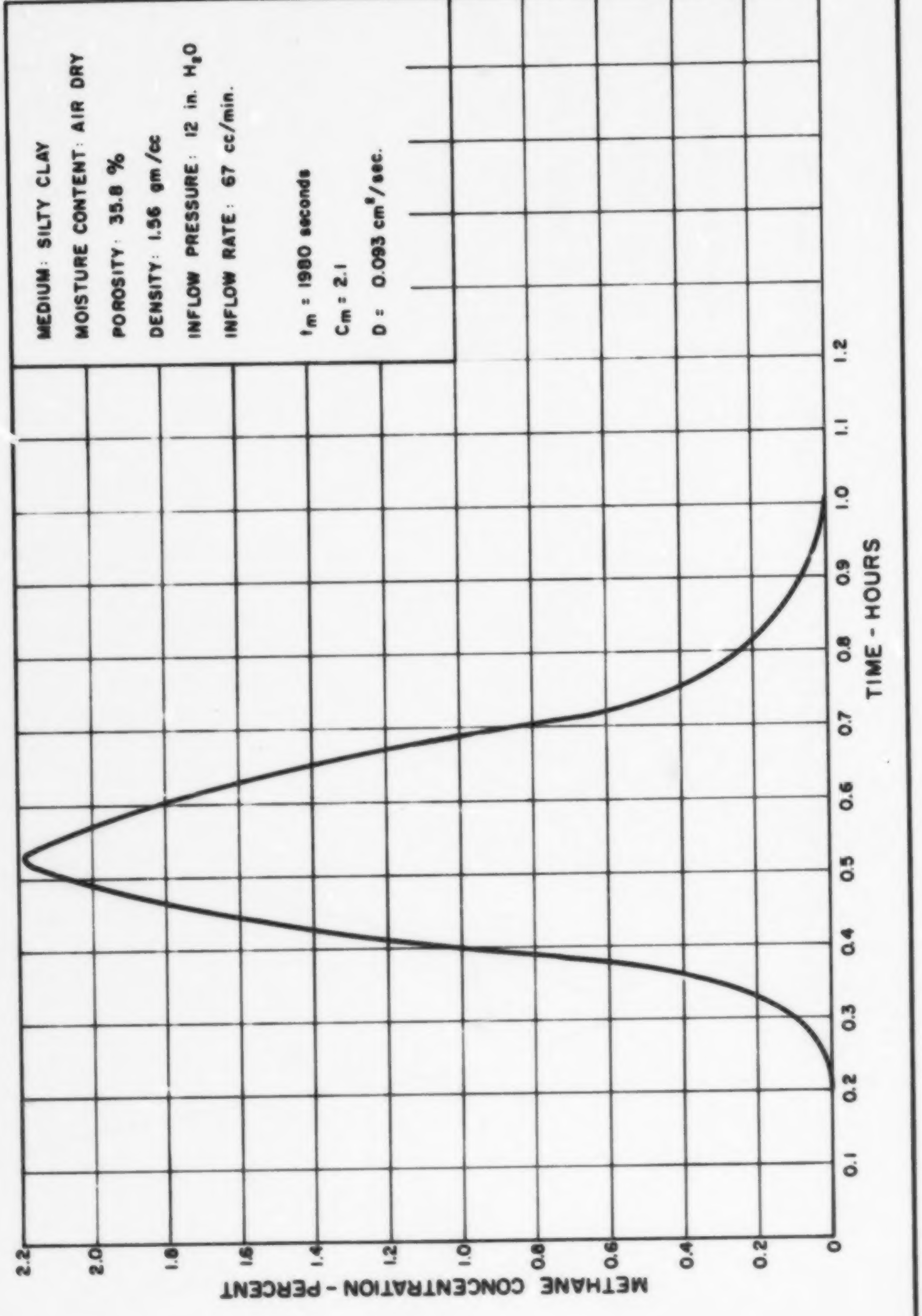


FIGURE IV-20

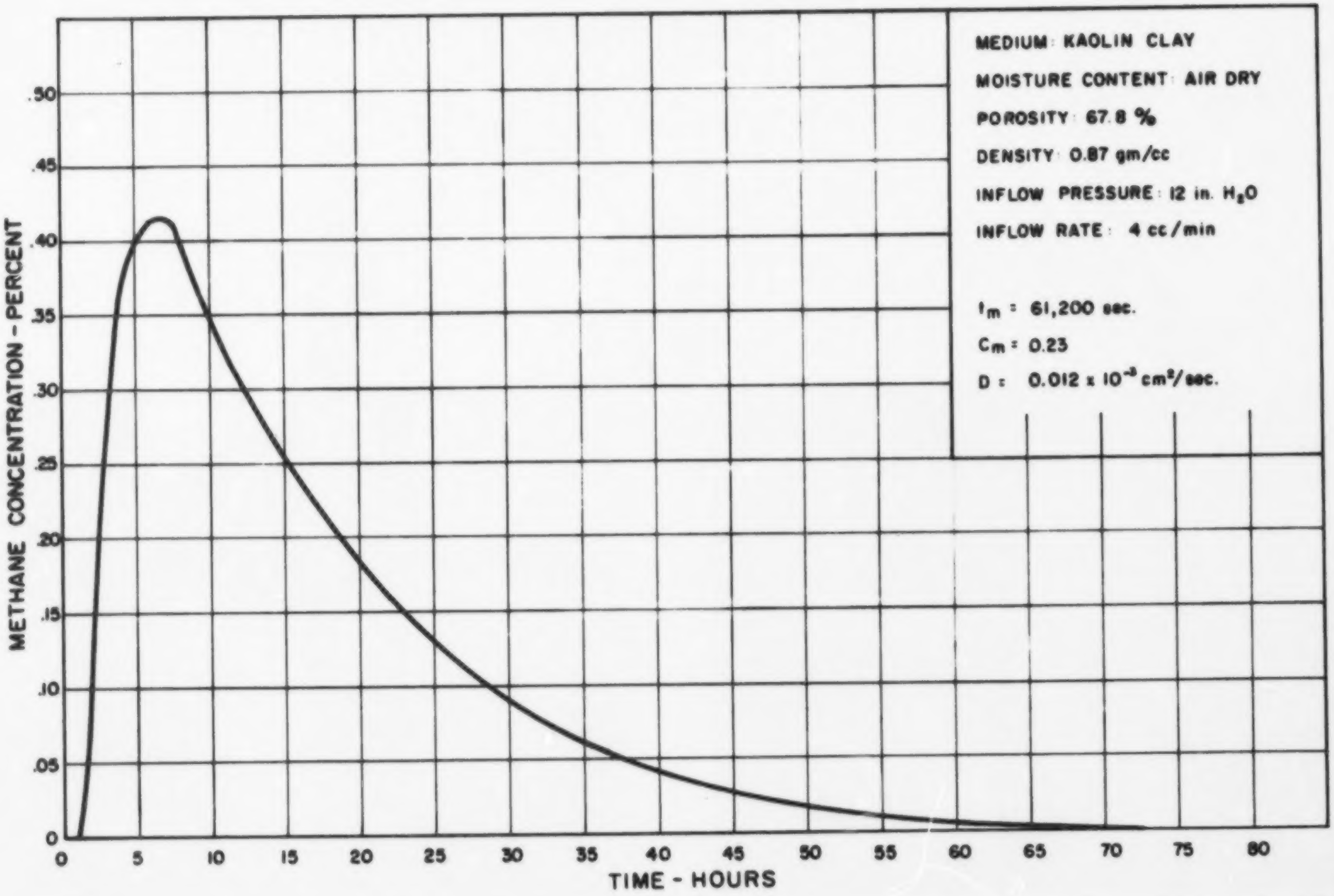
METHANE CONCENTRATION HISTORY - TEST NO. 14



ENGINEERING-SCIENCE, INC.

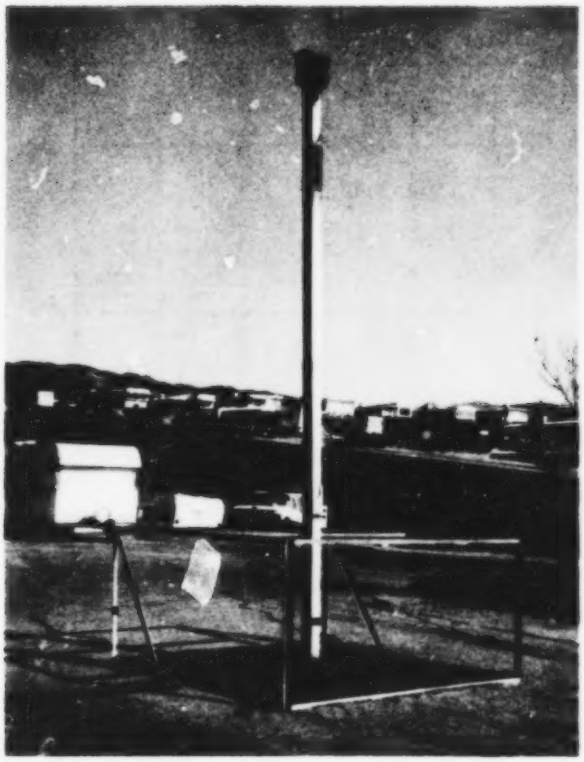
FIGURE IV-21

METHANE CONCENTRATION HISTORY - TEST NO. 15



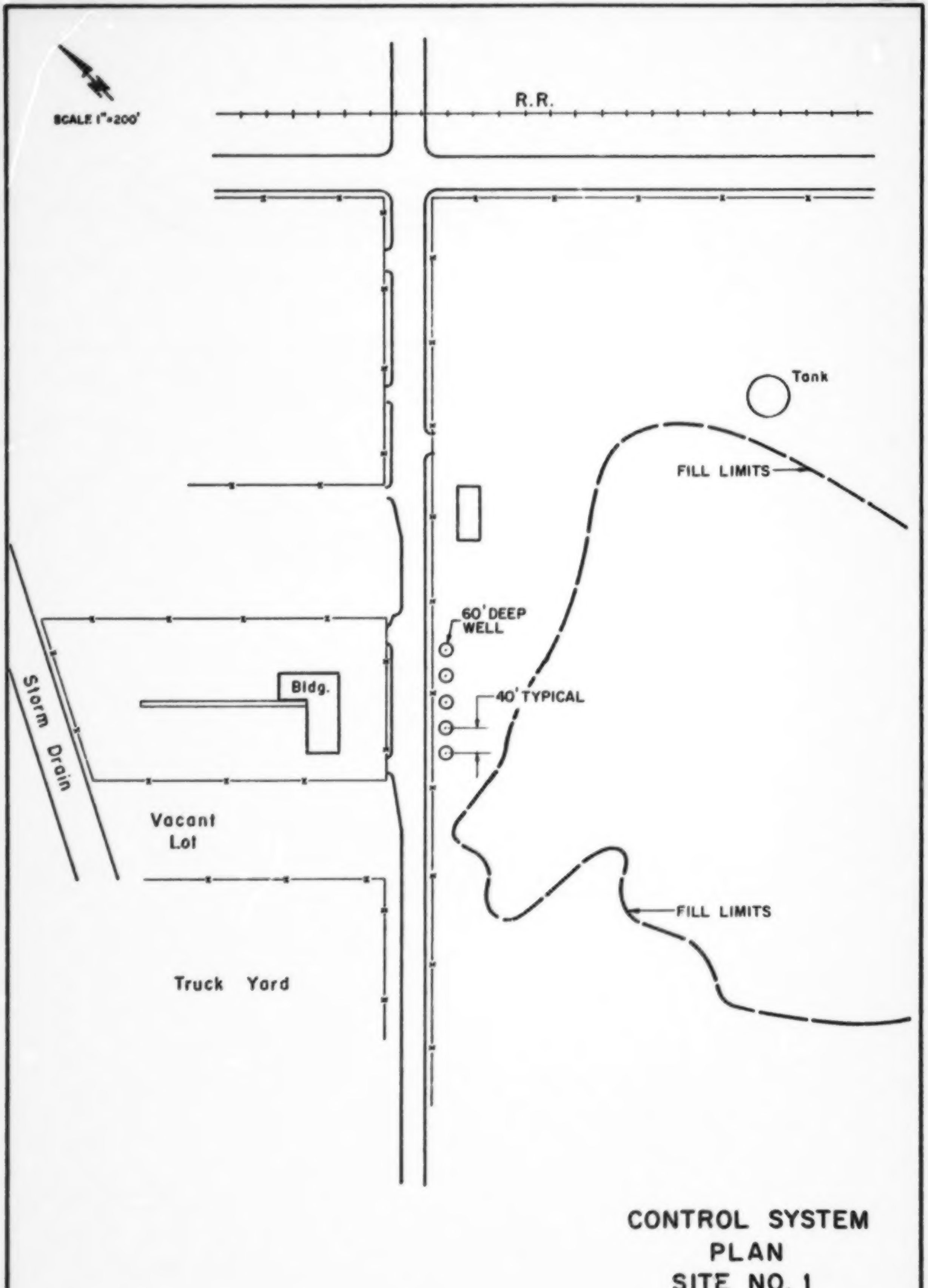
ENGINEERING-SCIENCE, INC.

FIGURE V-1



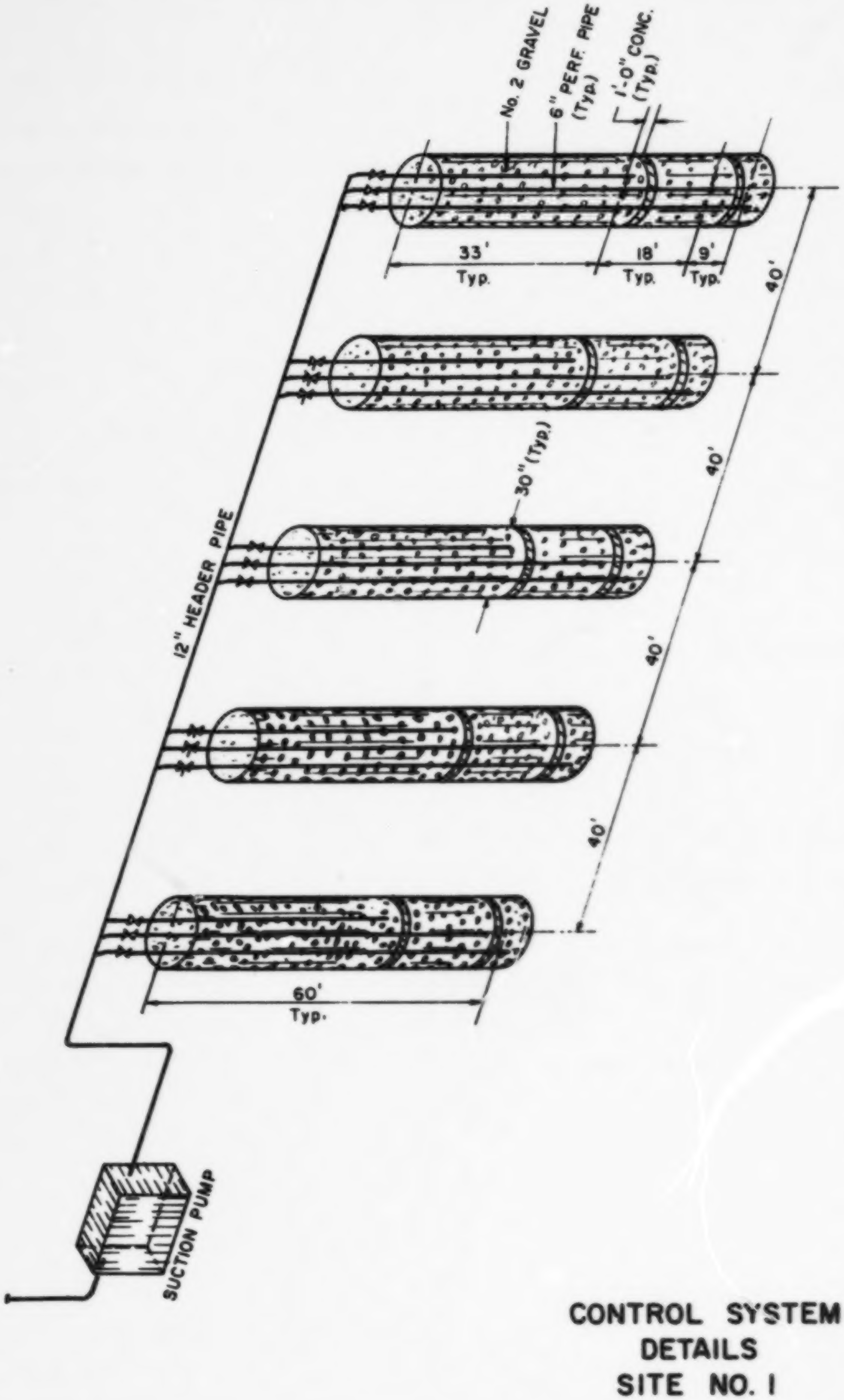
RESEARCH SITE NO. 4
Gas control device installed to burn gas and eliminate odors.

RESEARCH SITE NO. 8
Gas control device.


SCALE 1"=200'
R.R.
Tank
FILL LIMITS
60' DEEP WELL
40' TYPICAL
Bldg.
Storm Drain
Vacant Lot
FILL LIMITS
Truck Yard

CONTROL SYSTEM
PLAN
SITE NO. 1

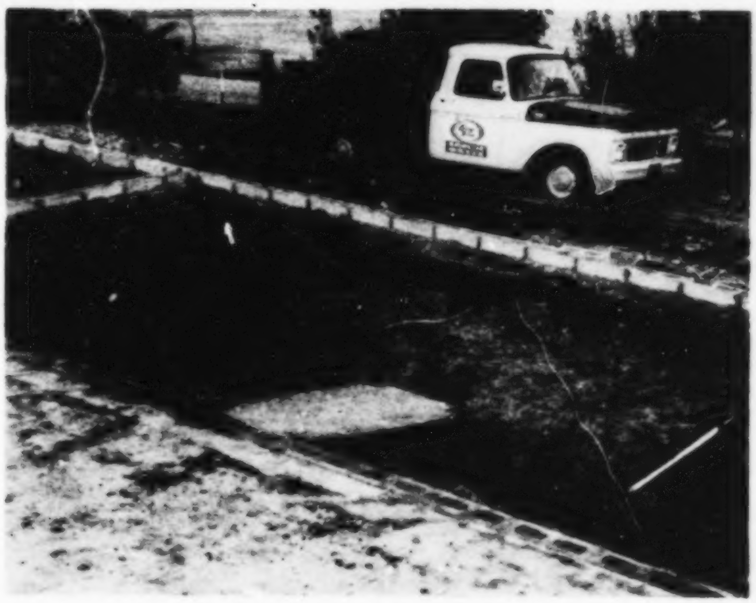
FIGURE V-3


No. 2 GRAVEL
6" PERF. PIPE (Typ.)
1'-0" CONC. (Typ.)
33' Typ.
18' Typ.
9' Typ.
40'
40'
40'
40'
30" (Typ.)
12" HEADER PIPE
60' Typ.
SUCTION PUMP

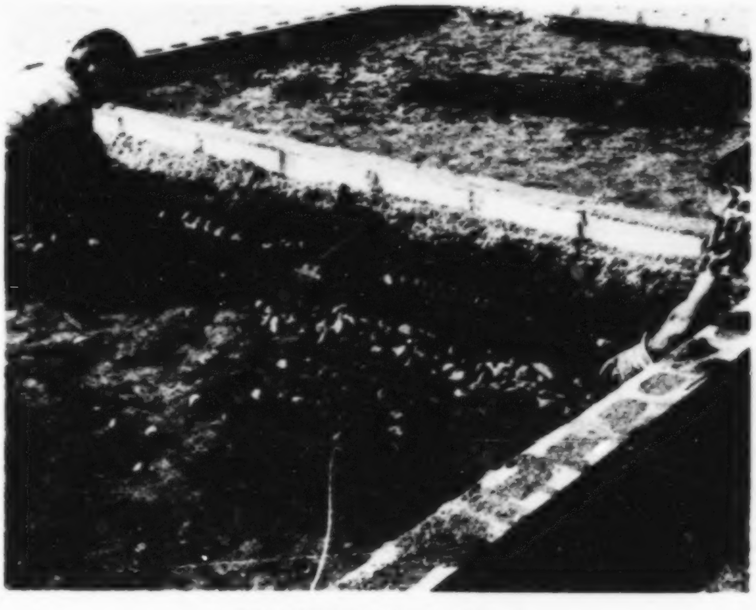
CONTROL SYSTEM
DETAILS
SITE NO. 1

ENGINEERING - SCIENCE, INC.

FIGURE V - 4

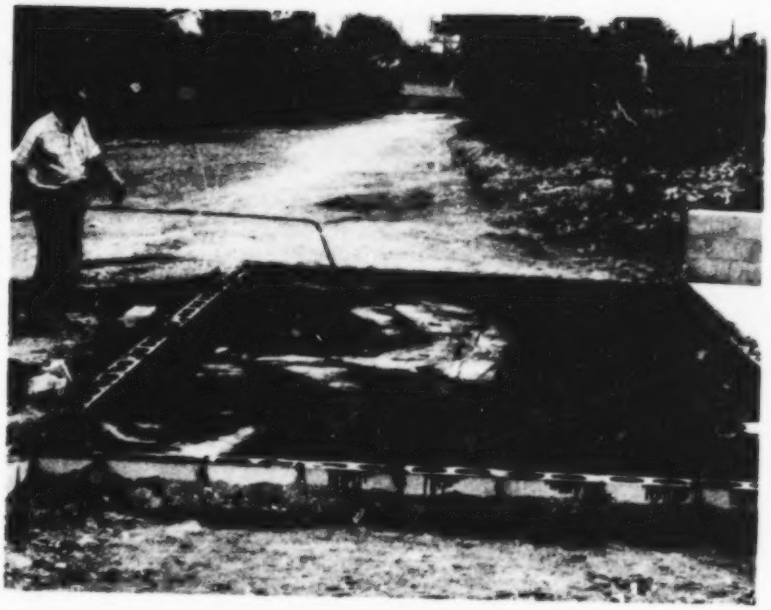


RESEARCH SITE NO. 5
Sub - barrier probe installation



RESEARCH SITE NO. 5
Sub - barrier venting pipe

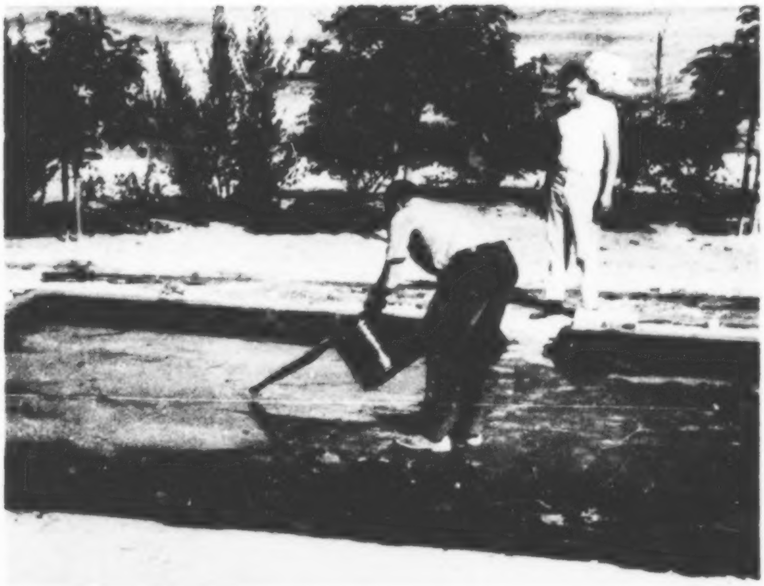
FIGURE V - 5



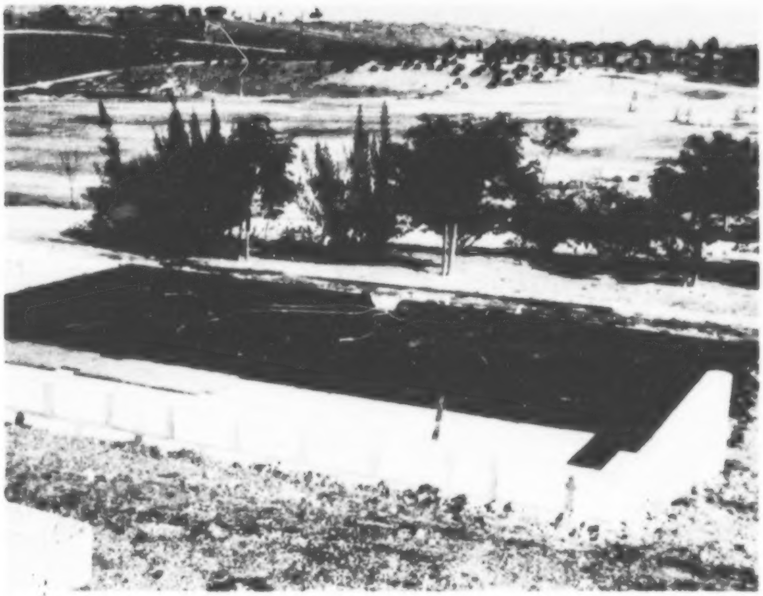
RESEARCH SITE NO. 5
Barrier initial prime-coat application

RESEARCH SITE NO. 5
Barrier liner installation

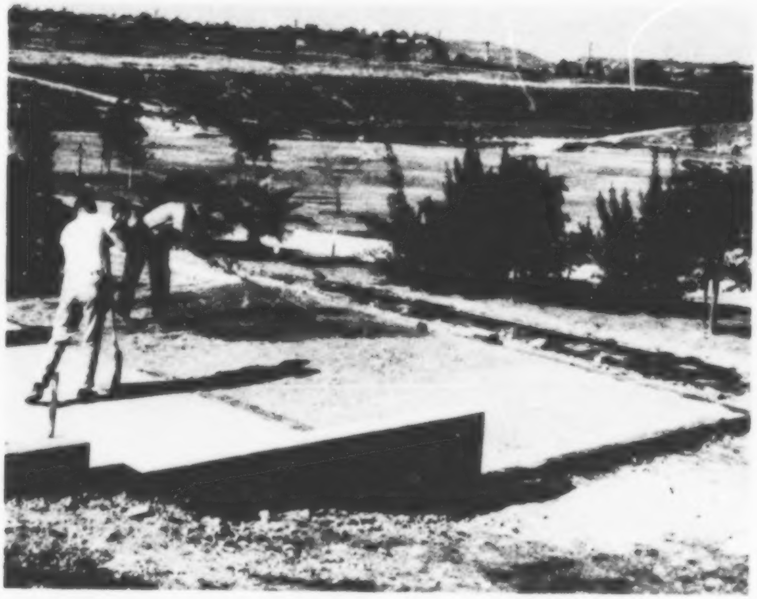
FIGURE V - 6



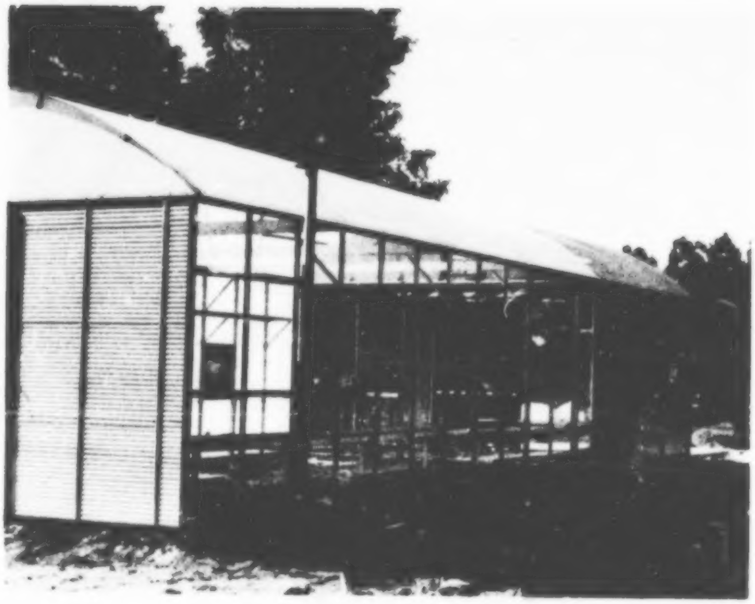
RESEARCH SITE NO. 5
Barrier final seal coat application



RESEARCH SITE NO. 5
Upper probe layout

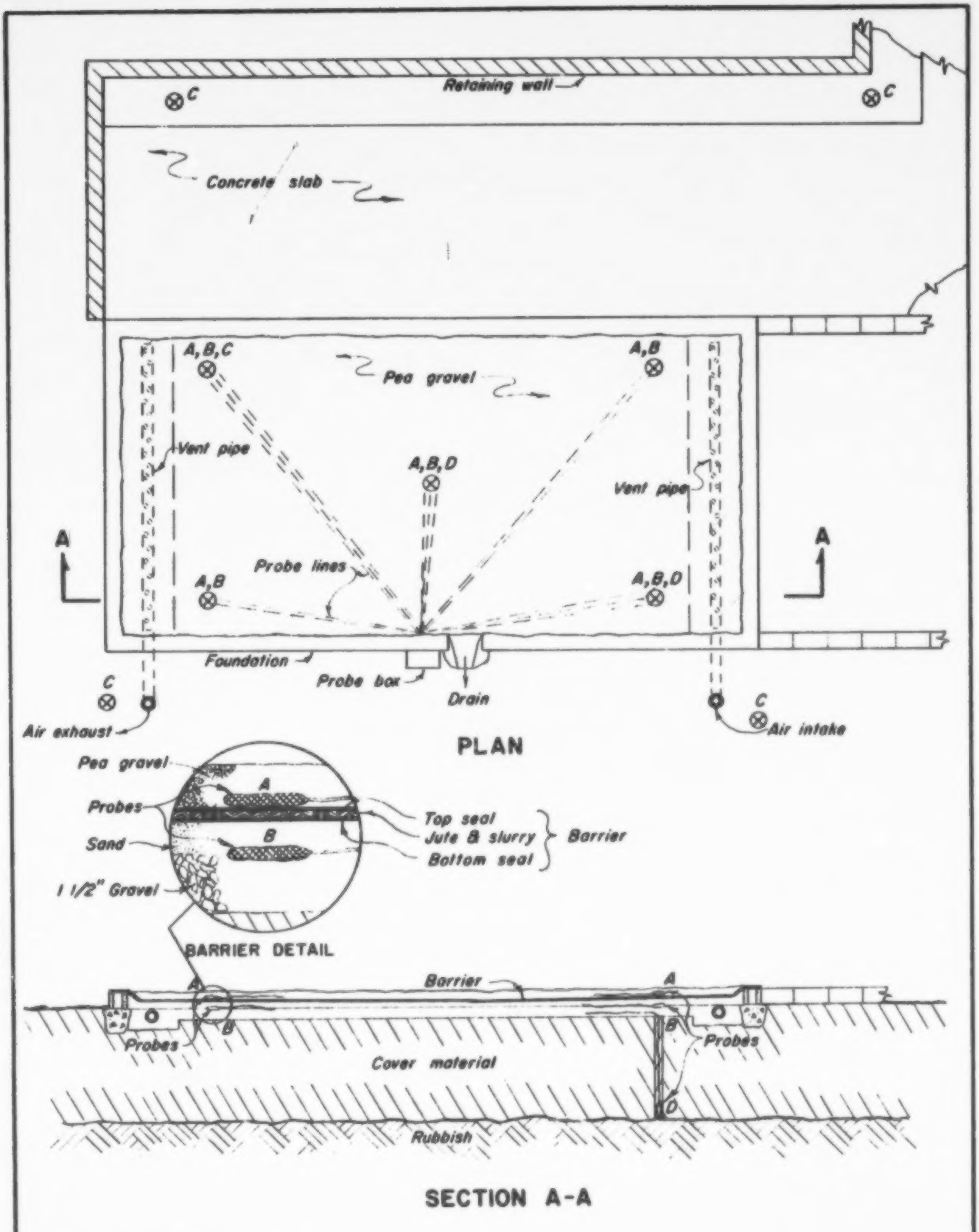


RESEARCH SITE NO. 5
Greenhouse gravel floor placement



RESEARCH SITE NO. 5
Greenhouse construction

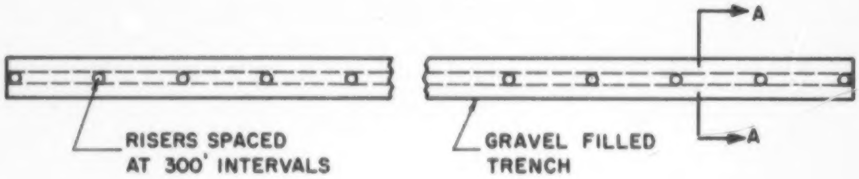
FIGURE V-8


Retaining wall
C
C
Concrete slab
Pea gravel
A,B,C
A,B
A,B,D
Vent pipe
Vent pipe
A
A
Probe lines
A,B
A,B,D
Foundation
Probe box
Drain
C
C
Air exhaust
Air intake
PLAN
Pea gravel
Probes
Sand
1 1/2" Gravel
A
B
Top seal
Jute & slurry
Bottom seal
Barrier
BARRIER DETAIL
Barrier
A
A
B
B
Probes
Probes
Cover material
D
Rubbish
SECTION A-A

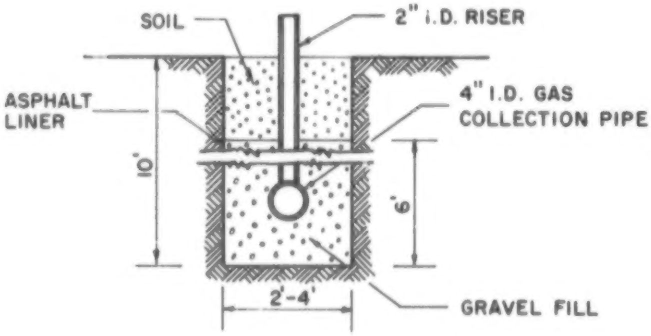
GAS PROBE LOCATIONS = ⊗
A - Probe above barrier
B - Probe below barrier
C - Probe in cover material
D - Probe in rubbish

CONTROL SYSTEM
SITE NO. 5

FIGURE V-9


A
A
RISERS SPACED AT 300' INTERVALS
GRAVEL FILLED TRENCH

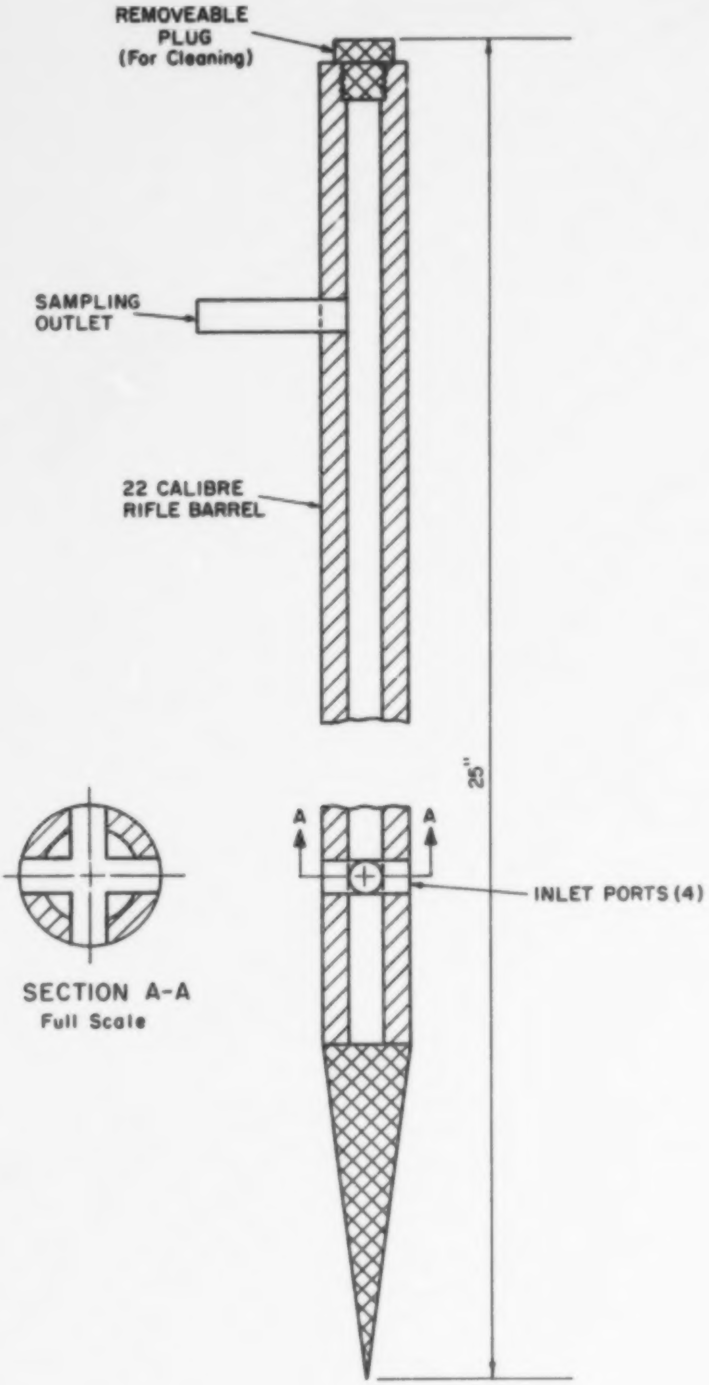
COLLECTION SYSTEM
PLAN VIEW
NOT TO SCALE


SOIL
2" I.D. RISER
ASPHALT LINER
4" I.D. GAS COLLECTION PIPE
10'
6'
2'-4'
GRAVEL FILL

SECTION A-A
NOT TO SCALE

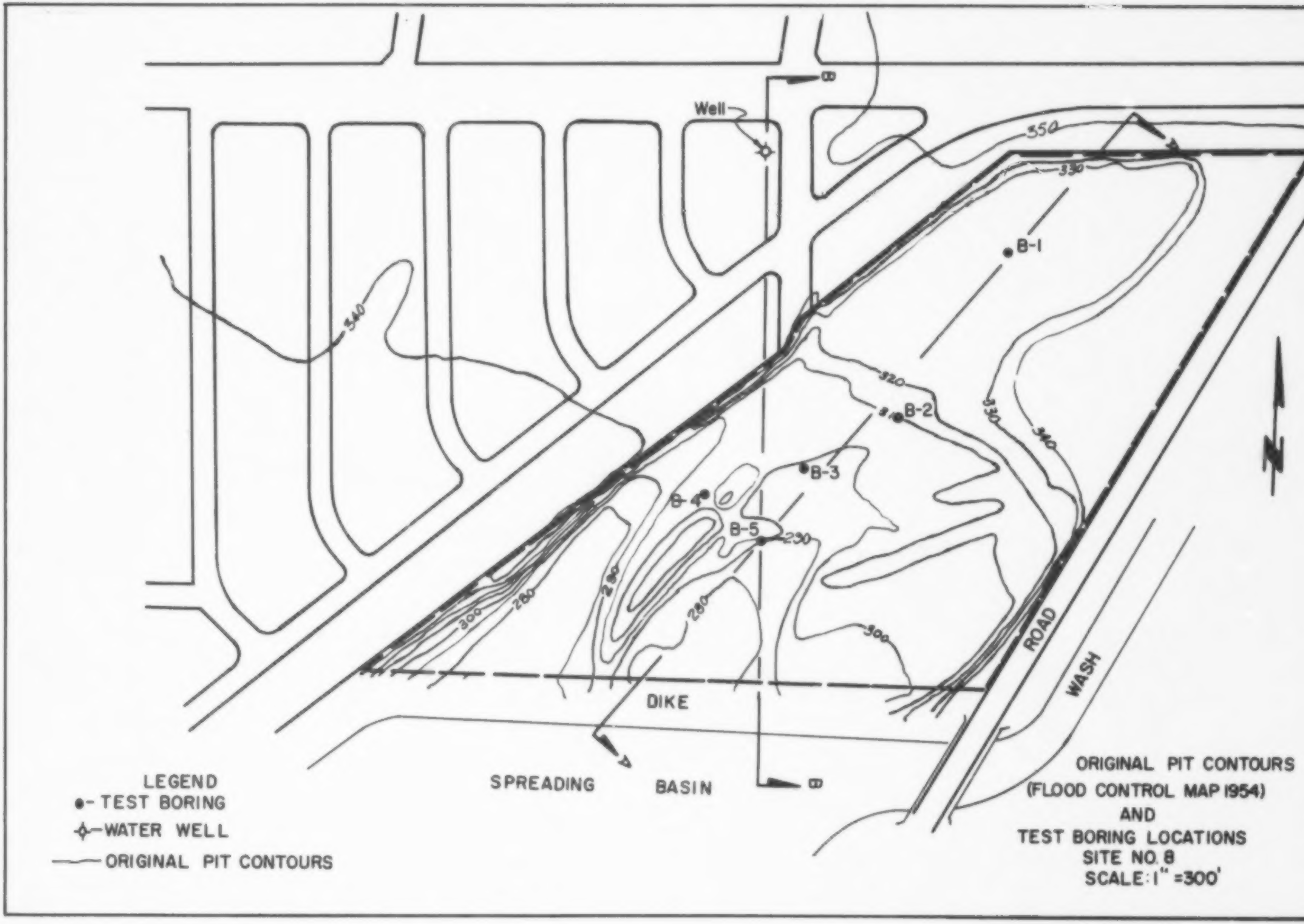
CONTROL SYSTEM
PLAN AND DETAILS
SITE NO. 8

FIGURE V-10


REMOVEABLE PLUG (For Cleaning)
SAMPLING OUTLET
22 CALIBRE RIFLE BARREL
25"
A
A
INLET PORTS (4)
SECTION A-A
Full Scale

PORTABLE FIELD METHANE SENSOR

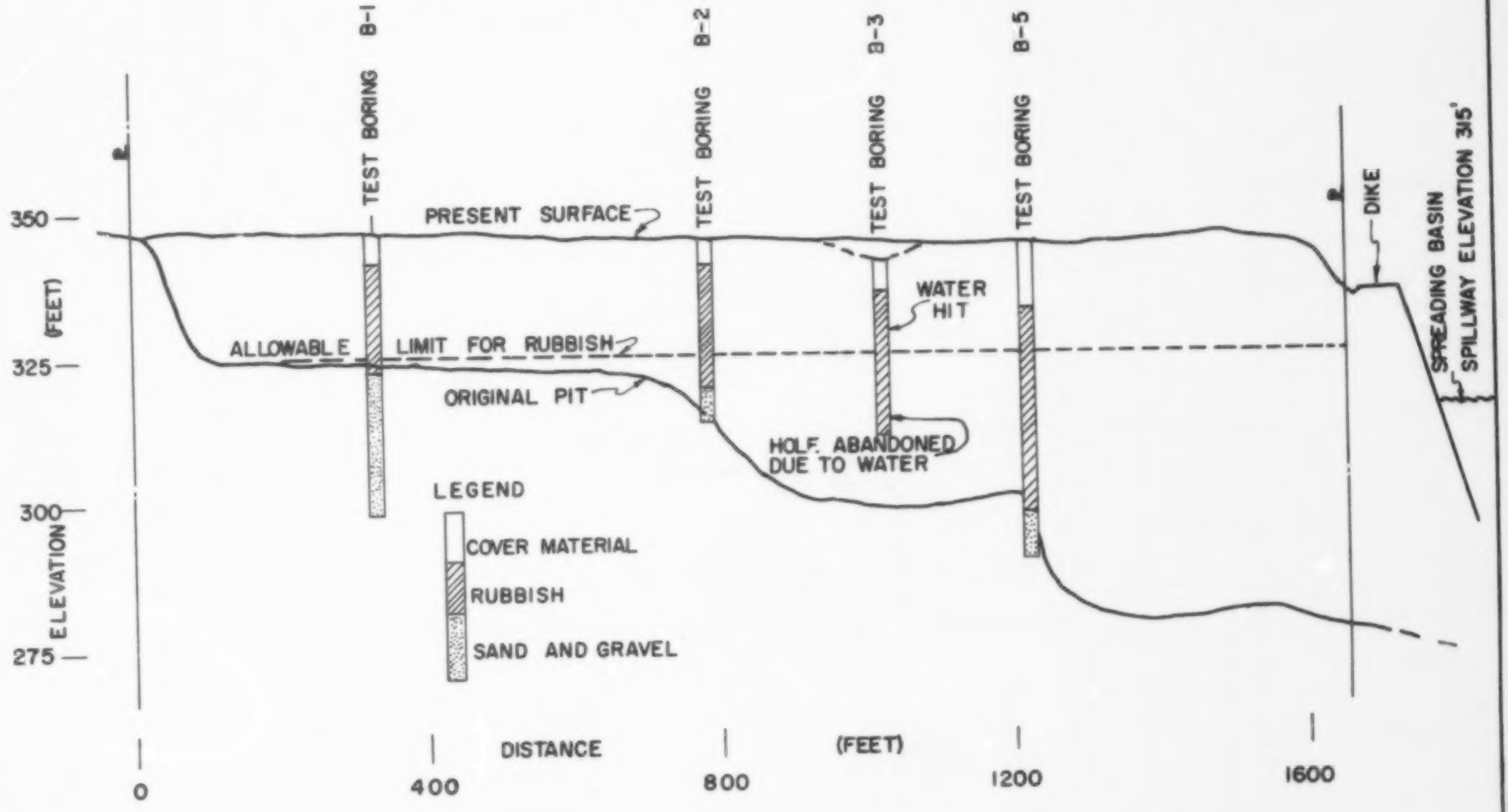
FIGURE VI-1



ORIGINAL PIT CONTOURS
(FLOOD CONTROL MAP 1954)
AND
TEST BORING LOCATIONS
SITE NO. 8
SCALE: 1" = 300'

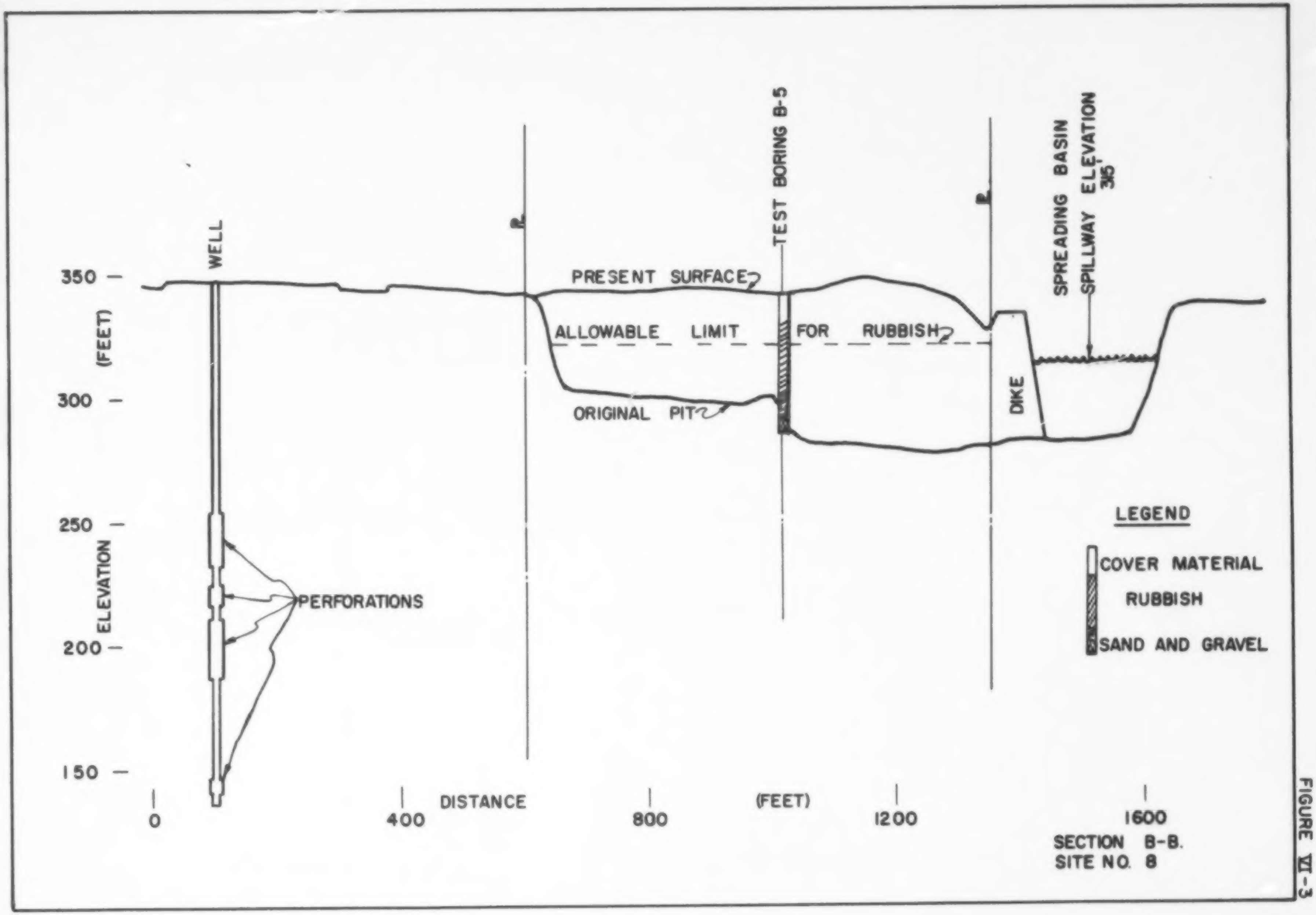
LEGEND
●- TEST BORING
⌖-WATER WELL
—ORIGINAL PIT CONTOURS
Well
B
B
A
A
B-1
B-2
B-3
B-4
B-5
350
330
340
320
300
290
280
230
ROAD
WASH
DIKE
SPREADING
BASIN
N

FIGURE VI-2


TEST BORING B-1
TEST BORING B-2
TEST BORING B-3
TEST BORING B-5
PRESENT SURFACE
ALLOWABLE LIMIT FOR RUBBISH
ORIGINAL PIT
WATER HIT
HOLF. ABANDONED DUE TO WATER
DIKE
SPREADING BASIN
SPILLWAY ELEVATION 315'
LEGEND
COVER MATERIAL
RUBBISH
SAND AND GRAVEL
350
325
300
275
ELEVATION (FEET)
0
400
800
1200
1600
DISTANCE (FEET)

SECTION A-A
SITE NO. 8

FIGURE VI-3


WELL
℞
TEST BORING B-5
℞
SPREADING BASIN
SPILLWAY ELEVATION
315'
PRESENT SURFACE
ALLOWABLE LIMIT FOR RUBBISH
ORIGINAL PIT
DIKE
PERFORATIONS
350
300
250
200
150
ELEVATION (FEET)
0
400
800
1200
1600
DISTANCE (FEET)
LEGEND
COVER MATERIAL
RUBBISH
SAND AND GRAVEL
SECTION B-B.
SITE NO. 8

OTHER SOLID WASTE DEMONSTRATION PROJECT REPORTS:

Project No.	Grantee	Report
D01-UI-00004	City of Madison, Wisconsin	Solid waste reduction/salvage plant; an interim report, City of Madison pilot plant demonstration project. Cincinnati, U.S. Department of Health, Education, and Welfare, 1968. 25 p.
D01-UI-00018	City of Santa Clara, California	Solid wastes landfill stabilization; an interim report. Cincinnati, U.S. Department of Health, Education, and Welfare, 1968. 146 p.
D01-UI-00026	Quad-City Solid Wastes Committee Paterson, New Jersey	Quad-City solid wastes project; an interim report, June 1, 1966 to May 31, 1967. Cincinnati, U.S. Department of Health, Education, and Welfare, 1968. 192 p.
D01-UI-00038	District of Columbia *Final Report: Phase 1*	Special studies for incinerators; for the Government of the District of Columbia, Department of Sanitary Engineering. Public Health Service Publication No. 1748. Washington, U.S. Government Printing Office, 1968. 80 p.
D01-UI-00060	City of Des Moines, Iowa	Collection and disposal of solid waste for the Des Moines metropolitan area; a systems approach to the overall problem of solid waste management; an interim report. Cincinnati, U.S. Department of Health, Education, and Welfare, 1968. 326 p.
D01-UI-00073	American Public Works Association Research Foundation, Chicago, Illinois	The Tezuka refuse compression system; a preliminary report. Cincinnati, U.S. Department of Health, Education, and Welfare, 1969. 47 p.
D01-UI-00080	Metropolitan Sanitary District of Chicago	Land reclamation project; an interim report. Cincinnati, U.S. Department of Health, Education, and Welfare, 1968. 338 p.

Single copies of the above publications may be obtained by writing to: U.S. Department of Health, Education, and Welfare, Public Health Service, Consumer Protection and Environmental Health Service, Environmental Control Administration, Bureau of Solid Waste Management, 222 East Central Parkway, Cincinnati, Ohio 45202.